

State of California  
Air Resources Board

Method 501

Determination of Size Distribution of  
Particulate Matter from Stationary Sources

Adopted: March 23, 1988  
Amended: September 12, 1990

Method 501  
Determination of Size Distribution of  
Particulate Matter Emissions from Stationary Sources

TABLE OF CONTENTS

1	Principle and Applicability
1.1	Principle
1.2	Applicability
2	Apparatus
2.1	Sampling Equipment
2.1.1	Right Angle Precollector
2.1.2	Nozzles
2.1.3	Cascade Impactor
2.1.4	Sampling Probe and Umbilical Lines
2.1.5	Condenser
2.1.6	Metering System
2.1.7	Gas Density Devices
2.1.8	Barometer
2.1.9	Safety Devices
2.1.10	Other Support Items
2.2	Analytical Equipment
2.2.1	Substrate Preparation
2.2.2	Sample Recovery
2.2.3	Analysis
2.2.3.1	Balances
2.2.3.2	Other Analytical Equipment
4.2.4.3	Sampling Train Preparation
4.2.4.4	Leak Checks
4.2.4.4.1	Lab Leak Checks
4.2.4.4.2	Cold Leak Checks
4.2.4.4.3	Hot Pre-Run and Post-Run Leak Checks
4.2.4.5	Run Sheet Instructions
4.2.4.5.1	Lab Pre-Run Entries (15 Items)
4.2.4.5.2	Stack Entries (32 Items)
4.2.4.5.3	Lab Post-Run Entries (12 Items)
4.2.4.6	Particulate Train Operation and Data Recording
4.2.4.7	Isokinetic Check
4.2.5	Sample Recovery
4.2.5.1	Unloading Impactor
4.2.5.2	Unloading Impactor

#### 4.2.6 Practical Problems

4.2.6.1 Nozzle Scraping

4.2.6.2 Particle Bounce

4.2.6.3 Overloading

#### 4.2.7 Multiple Sampling Runs

#### 4.2.8 Analytical Balancing Protocol

4.2.8.1 Pre- and Post-Test Desiccation

4.2.8.2 Balance Operation

### 5 Calibration

5.1 Pitot Tube

5.2 Precollector Nozzle

6.1.11 Dry Gas Meter Volume and Leakage Correction

6.1.12 Volume of Water Vapor

6.1.13 Moisture Content

6.1.14 Acetone Blank Concentration

6.1.15 % Isokinetic

6.1.16 Acetone Wash Residue

6.1.17 Total Particulate Weight and Blank Weight Corrections

6.1.18 Particulate Concentration

6.1.19 Stage Cut Points

6.2 Data Forms

6.3 Reporting Requirements

6.4 Computer Programs

### 7 Quality Assurance and Control

7.1 Acceptable Results

7.1.1 General Test Criteria

7.1.1.1 Blank Impactor Gains

7.1.1.2 Minimum Number of Runs

7.1.2 Criteria for Individual Runs

7.1.2.1 Reproducibility of Control Weights

7.1.2.2 Reynolds Number Limit

7.1.2.3 Bounce Prevention

7.1.2.4 In-Situ Sampling

7.3.4 Top Entry Ports

7.3.5 Small Ducts

7.3.6 Size Segregated Samples for Chemical Analysis

### 8 References

METHOD 501  
DETERMINATION OF SIZE DISTRIBUTION OF  
PARTICULATE MATTER EMISSIONS FROM STATIONARY SOURCES

1 PRINCIPLE AND APPLICABILITY

Skilled operators are needed for proper operation of cascade impactors, the subsequent analysis of the sample, and presentation of the data. As the skill, experience, and judgment of the user are important factors in the successful application of this method, any deviations from recommendations should be reported.

1.1 PRINCIPLE

Particulate matter is withdrawn isokinetically from the source and segregated by size in a cascade impactor at the sampling point exhaust conditions of temperature, pressure, etc. Cascade impactors use the principle of inertial separation to size segregate particle samples from a particle laden gas stream. The mass of each size fraction is determined gravimetrically.

1.2 APPLICABILITY

This method is applicable in ducted source sampling environments with a particulate mass concentration range of 0.005 to 50 grains per cubic foot, a pressure range of -5 to +20 inches water gauge, a temperature range of 32 to 840°F and a velocity range of 10 to 100 feet per second.<sup>1</sup>

DETERMINATION OF PM<sub>10</sub> EMISSIONS FROM STATIONARY SOURCES

Any rule or regulation which refers to this test method for the purposes of determining PM<sub>10</sub> emissions should specify the procedures by which such emissions are defined. PM<sub>10</sub> is defined for ambient sampling, but for source sampling, carefully detailed sampling and analytical procedures should be referenced and the results defined as PM<sub>10</sub>.

The recommended procedure is to determine a mass fraction of PM<sub>10</sub> by ARB Method 501 while conducting a total PM mass emissions test using ARB Method 5. Then the mass fraction (of those particles with aerodynamic diameters equal to or less than ten microns) multiplied by the total emissions is defined as the PM<sub>10</sub> emissions. Any rule or regulation so written should specify whether or not the impinger catch from Method 5 should be included in the calculation.

Figure 1 on page 3 of this method shows a sampling train employing the minimum apparatus necessary for the determination of a PM<sub>10</sub> mass fraction using a cascade impactor. After the construction of a particle size distribution curve following the

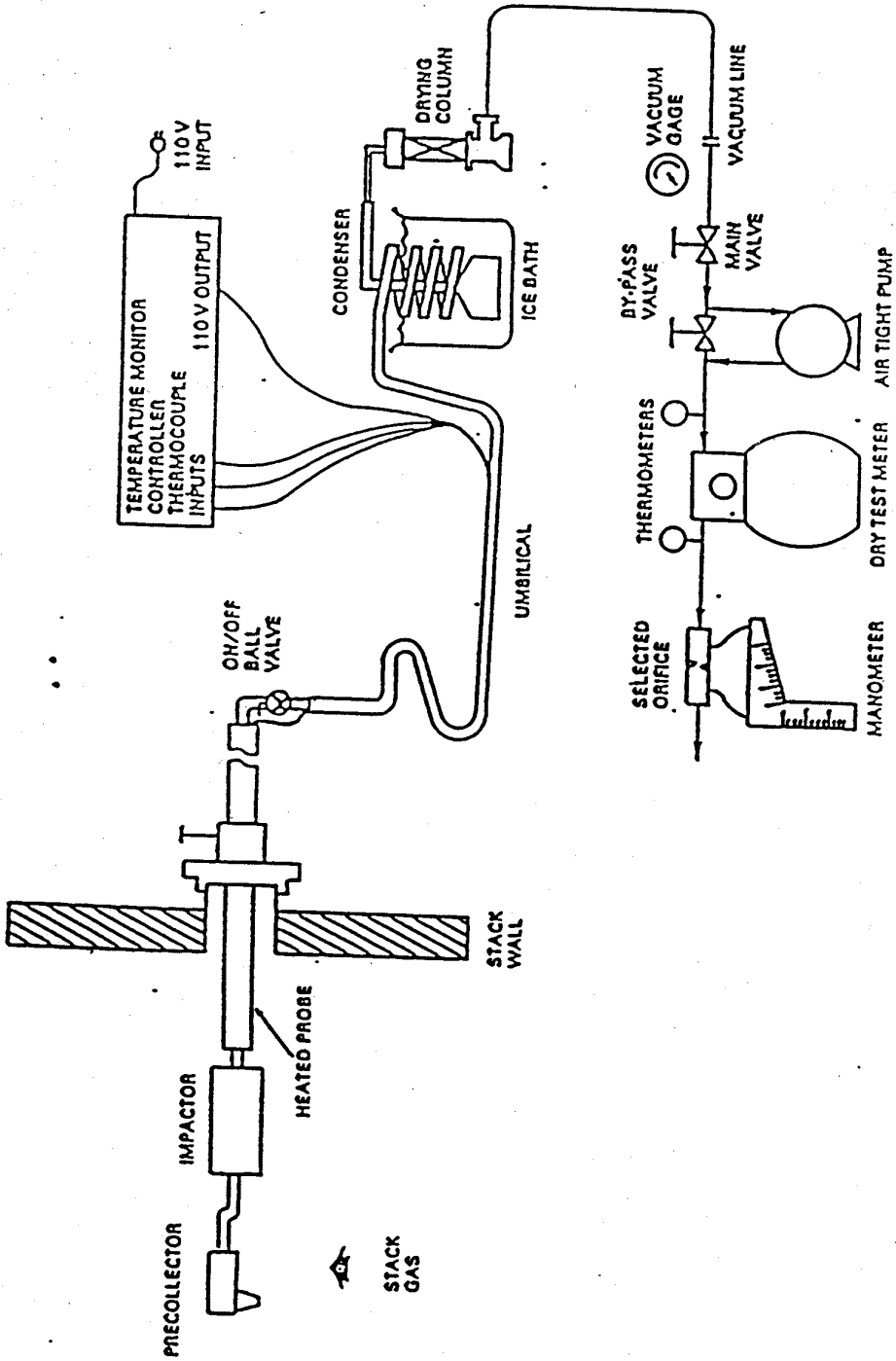
---

<sup>1</sup> Much of the text of this method was taken from the "Procedures Manual for the Recommended ARB Particle Size Distribution Method (Cascade Impactors)," hereafter referred to as "Manual."

impactor manufacturer's instructions, the PM<sub>10</sub> mass fraction should be taken as the mass fraction of particles with aerodynamic diameters less than ten microns.

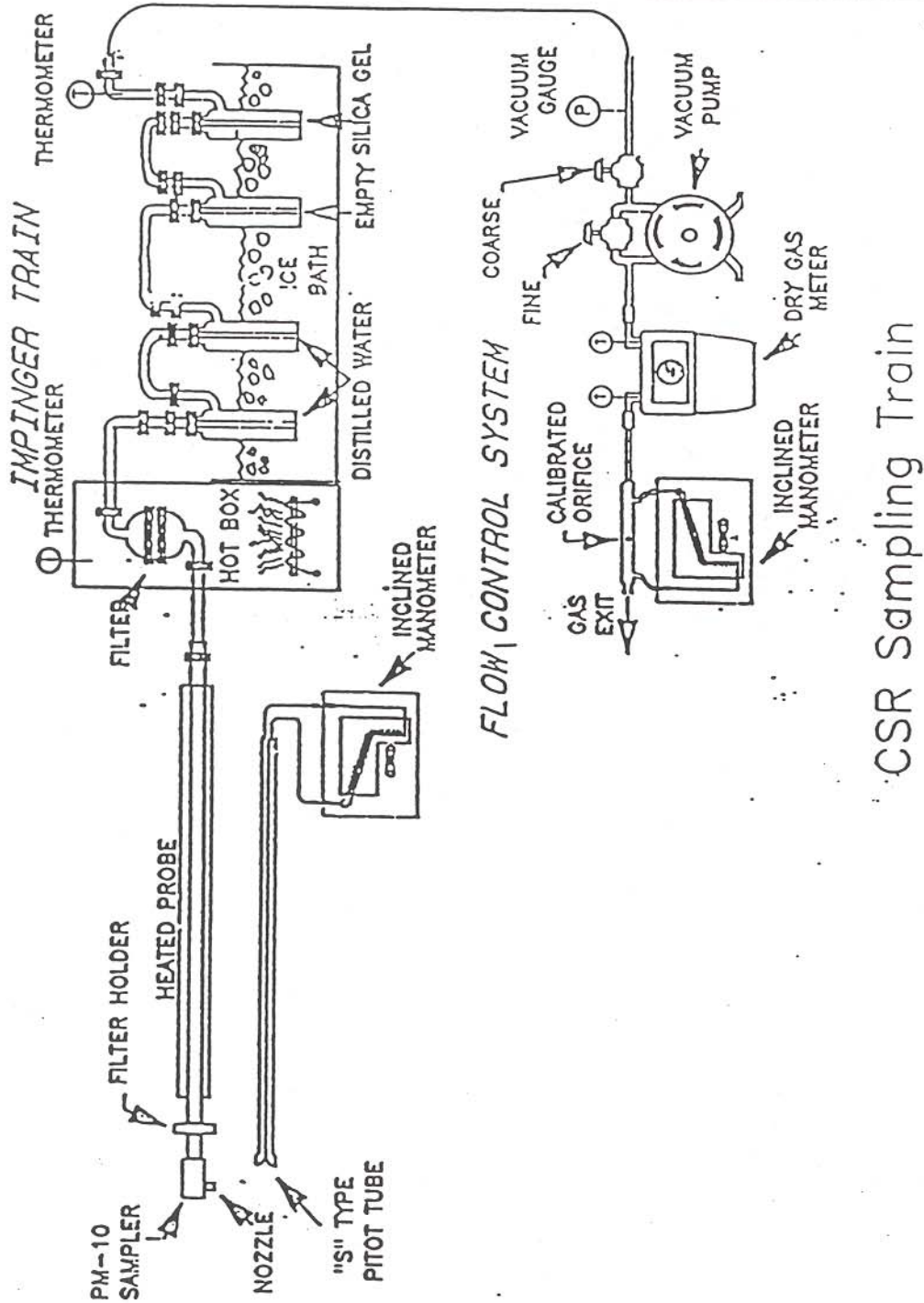
Figure 2 on page 4 is EPA's schematic diagram of a constant sampling rate (CSR) sampling train. The reference for Figure 2 is EPA's Method 201A—Determination of PM<sub>10</sub> Emissions (Constant Sampling Rate Procedure), published in the Federal Register/Volume 54 No.107/Tuesday, June 6, 1989/Proposed Rules/pages 24235-24247. This sampling train allows the PM<sub>10</sub> mass emissions determination from only one train, but does not allow consistent comparisons with a Method 5 database which includes condensable particulate mass. If this is not an important issue, then the CSR alternative may be used.

Figure 1



*Cascade Impactor particulate sampling train for noncondensable particulate (modified EPA Method 5 Train).*

Figure 2



## 2 APPARATUS

The following paragraphs describe the apparatus used with cascade impactors.

- 2.1 A schematic of the sampling train is shown in Figure 1. The right angle precollector and cascade impactor are mounted on the modified probe of a standard Method 5 sampling train. The pitot head normally used on a standard Method 5 sampling train is not used with impactors. The flow metering orifice on the dry gas meter may need to be changed to an appropriate size for the desired impactor flow rate. Since the impactor is operated in-situ, the filter/oven section of the Method 5 train is not used. This is analogous to using Method 5 sampling equipment to run Method 17 Emission Tests. The reader is referred to U. S. E. P. A. Publication APTD-0581 (Construction Details of Isokinetic Source-Sampling Equipment) (Martin, 1971) for a more detailed equipment description. All in-situ components should be constructed of stainless steel for purposes of temperature tolerance, ruggedness, and resistance to corrosive flue gases. High temperature heating tapes permit the same probe to be used in hot side as well as cold side sampling situations. Method 5 sampling trains are available from numerous commercial vendors. The following paragraphs describe the various components of the sampling train.

NOTE: The condenser in Figure 1 should be removed and replaced by a Method 5 type impinger train as shown in Figure 2 if condensible emissions are to be included in the PM<sub>10</sub> mass fraction determination. A determination of total PM<sub>10</sub> emissions (including condensible emissions) should have condensible emissions (impinger catches) included in both the Method 5 and Method 501 determinations on which it is based.



INTENTIONALLY LEFT BLANK

### 2.1.1 RIGHT ANGLE PRECOLLECTOR

In most situations the use of a right angle precollector is essential. The precollector serves to (1) turn the sample stream through a 90° angle and (2) help prevent overloading of first impactor stage. If the port arrangement distribution of the sample stream does not cause over loading problems with the first impactor stage, then the precollector is not necessary.

The curved nozzles (90° Bend and Buttonhook) used with Methods 5 and 17 are unacceptable for use with particle sizing devices because of high particulate losses in the nozzle. At moderate to high duct velocities it is quite possible for such a nozzle to have a 50% collection efficiency diameter,  $D_{50}$ , smaller than the  $D_{50}$ 's of the later stages (See Section 4.3.1.2, Nozzle Choice Flowrate and Impactor Stages).

If the capacity of the upper stage needs to be increased to permit collection of weighable quantities at the lower stages, the precollector provides a means of accomplishing this.

The right angle precollector is separate from the impactor and as such can be attached to almost any impactor which is operable at a compatible flow rate. The Zoltec Brink Model C cascade impactor has a built-in cyclone that serves as a right angle precollector to this low flow rate sampler. The Brink is designed for inlet sampling situations.

### 2.1.2 NOZZLES

When attached to the right angle precollector, the nozzle should not inhibit entry through a four inch diameter port. However, if the impactor can be rotated into flow it may not be necessary to use a precollector. As discussed earlier, the curved nozzles (90° Bend and Buttonhook) used with Methods 5 and 17 are unacceptable for use with particle sizing devices because of high particulate losses in the nozzle. The nozzles should have a sharp leading edge. The inside of the nozzle should have an even taper from the inlet diameter to a correct exit diameter for the particular precollector. It is important that all nozzles have the same exit diameter since this is one of the critical dimensions in the aerodynamic performance of the precollector (inlet jet diameter).

A range of nozzle sizes is needed for isokinetic sampling. The recommended range is from 1/8 to 1/2 inch (3.2 to 12.7 mm) diameter in increments of 1/16 inch (1.6 mm). For inlet sampling with a low flow rate impactor, it may be necessary to use smaller increments in nozzle diameter. Problems with nozzle pluggage establish a minimum diameter of about 0.0550 inches (1.4 mm, wire gauge drill size No. 54). Note that a 1400 um particle will plug this nozzle. Nozzles should be calibrated as described in Section 5, Calibration. Emergency field repairs can be made using a sharp round tapered metal tool such as an awl or a scribe. Care should be taken to avoid flaring the thin metal edges of the nozzle when performing the emergency repair. Repaired

nozzles must be so noted in equipment log books and recalibrated before use. A dial caliper (0.001 inch) as described in Section 5.2 should be on hand for this calibration.

### 2.1.3 CASCADE IMPACTOR

Appendix B of the Manual and Section 8 of this method give a list of current commercially available cascade impactors suitable for use as in-situ stack samplers (An acceptable impactor is one which produces acceptable results per the quality assurance and control criteria in Section 7.) Operation of one of the suitable impactors shall be in substantial conformance with the manufacturer's operating instructions. All of these impactors are designed with an internal filter holder. The calibration of the impactor type used must have been verified as described in Section 5.9, Impactor Stage Constants, for the configuration to be used (choice of substrate material and stages used). The Pollution Control Systems (University of Washington) Mark V Cascade Impactor together with an accessory right angle precollector and nozzle set (EPA/SoRI design) will meet the performance criteria of this test method in proper operation. Other impactors may be acceptable, as mentioned above; the examples given in this method are all for this manufacturer as a matter of consistency, not endorsement. The Mark V impactor is of an in-line design permitting the user to choose the appropriate stages for a given sampling situation (inlet), outlet, stack velocity, temperature, etc). The right angle precollector's connecting tube serves as a single jet first stage (zero stage) for the impactor and uses a solid disk-shaped collection substrate rather than the donut-shaped collection substrates used with the multi-jet stages. The impactor design requires that the solid disk must be used to direct the airflow to the subsequent multi-jet stages. Up to ten of these multi-jet stages may be selected as described from the twelve multi-jet stages furnished with the Mark V (i.e. there are two extra jet plates). Spacers may be used to permit operation with fewer than eleven stages. The preferred configuration is to use the single jet inlet followed by six multi-jet stages with one disk-shaped collection plate, seven donut-shaped collection plates respectively and two filters. The second filter serves as a quality control check. The extra donut-shaped collection plate is loaded with the selected substrate material and inserted upside down directly behind the collection plate of the last stage. This extra substrate is out of the gas flow path and thus never subjected to particulate matter. It serves as a quality control blank for the individual run and quantifies handling losses, balance changes, flue gas interaction, etc. Spacers may be used in the Mark V shell or a shorter Mark III shell may be used to make the impactor lighter and easier to traverse in and out of small ports with long probes. Viton-o-rings and Teflon inserts (at the filter) are normally used with this impactor. For high temperature applications metal o-rings and Kapton inserts may be substituted for the Viton and Teflon.

A filter holder and filter are needed to perform the blank impactor run described in Section 4.3.2. The filter is attached to the impactor inlet in place of the precollector and prevents particulate from entering the impactor, thus providing a quantitative measure of substrate flue gas interactions. Method 17, Section 2.1.2 describes a suitable filter. Nozzles are not required. Filter sizes commonly used are 47 mm or 63 mm.

#### 2.1.4 SAMPLING PROBE AND UMBILICAL LINES

A pitot tube may be used as part of the sampling train if desired but is not required. Velocity profile information is obtained prior to the sampling run by performing a velocity traverse using Method 2. The sampling flow rate, nozzle, and sampling points are selected based on this velocity traverse.

The sampling probe and umbilical lines are the same as those for a Method 5 train. The internal tubing of the probe should be stainless steel. The probe should be heated. The probe length should be sufficient to reach all traverse points.

#### 2.1.5 CONDENSER

The impinger system described in Method 5 shall be used.

#### 2.1.6 METERING SYSTEM

The metering system is the same as that for a Method 5 Sampling Train with the exception that in sampling situations requiring low impactor flow rates it may be necessary to use a smaller orifice than the standard 0.180 inch ID orifice. Construction of such smaller orifices is the same as for the standard Method 5 orifice except that a smaller diameter (e.g. 0.130, 0.093, and 0.059 in. i.d.) is used to obtain a higher pressure drop reading for the lower flows. These orifices should be calibrated as described in Section 5.4.

#### 2.1.7 GAS DENSITY DEVICES

Temperature sensor and pressure gauges, are described in Sections 2.3 and 2.4 of Method 2, and gas analysis equipment is described in Method 3. Data from Method 100, where applicable, may also be used.

#### 2.1.8 BAROMETER

A mercury, aneroid, or other barometer capable of measuring atmospheric pressure to within 2.5 mm Hg (0.1 in. Hg) may be used. In many cases, the barometric reading may be obtained from a nearby national weather service station, in which case the station value (which should be the absolute barometric pressure, not corrected to sea level) shall be requested and an adjustment for elevation differences between the weather station and sampling point shall be applied at a rate of minus 2.5 mm Hg (0.1 in. Hg) per 30 m (100 ft) elevation increase.

## 2.2 ANALYTICAL EQUIPMENT

### 2.2.1 SUBSTRATE PREPARATION

See Section 4.2.2

### 2.2.2 SAMPLE RECOVERY

Various items are used in the sample recovery process. A polyethylene wash bottle may be used to washdown the nozzle with acetone after cleaning the exterior and dry brushing the larger particles onto the precollector substrate with a small camel hair or nylon bristle brush. Note that acetone should not be stored in polyethylene bottles for longer than one month. A clean nozzle brush is used with the acetone washdown. The nozzle brush should have nylon bristles, a stainless steel wire handle and may be properly sized for the probe nozzle. For small nozzles, ultrasonic cleaning may be used. If the probe wash is to be evaporated on site, glass sample storage containers will not be needed. If post-test evaporation is to be done in the laboratory (where a vented hood is available) the wash should be stored in properly labeled glass sample bottles. These bottles should be chemically resistant, borosilicate glass, 500 mL or 1000 mL, with screw cap liners. The liners should be either be rubber-backed Teflon or constructed so as to be leak-free and resistant to chemical attack by acetone. The acetone rinse is then carefully evaporated in a preweighed aluminum evaporation dish placed on a hot plate. Use extreme care as acetone is highly flammable and has a low flash point. A ring stand and funnel are helpful during washdown.

A graduated cylinder (rugged plastic is recommended) is used to measure the volume of water removed during the sample run by the ice bath condenser or impingers. The cylinders should not have graduations larger than 2 mL. This will permit determinations to the nearest 1 mL. The condensers are followed by silica gel drying columns. Gravimetric determinations of water uptake by the silica gel may be made using a lab balance capable of weighing to the nearest  $\frac{1}{2}$  g or less. The conversion factor 1 g H<sub>2</sub>O = 1 mL H<sub>2</sub>O is then used to obtain moisture volumes.

Petri dishes (plastic is recommended) are used to protect the substrates. Each petri dish should be clearly labeled with the substrate identification number. Prior to the initial pre-run weighings and the post-run weighings the petri dishes are placed in airtight desiccators (plastic food storage containers work well) containing silica gel.

### 2.2.3 ANALYSIS

#### 2.2.3.1 BALANCES

Various analytical equipment is needed for the on-site laboratory where the impactors are loaded and unloaded and the substrates are weighed. The most important of these items is the analytical balance. Accurate weighing of the particulate matter collected on the impactor substrates requires a balance having a sensitivity of 0.01 mg or better.

Several electrobalances marketed have the insensitivity to vibration required for field use, as well as weighing chambers and pans large enough to accommodate flat unfolded substrates. Some may require modification if abnormally large substrates are to be weighed. Various items are used with the analytical balance. These include tare weights, Class S standard calibration weights, smooth tweezers for handling the calibration weights, tweezers for handling the substrates, control weights, thread strips, special large sample pans, and tape for bundling petri dishes with substrates from the same run.

If at all possible, the substrates should be weighed in the on-site laboratory rather than being transported back to the home laboratory for weighing. The collected particulate matter will be lying on an open substrate and distances can easily cause some material to be spilled over to the petri dish. Because the weight changes are so small (less than 15 mg per stage) any losses during transport can represent a large percentage of the total weight change.

#### 2.2.3.2 OTHER ANALYTICAL EQUIPMENT

Other on-site lab items include plastic desiccators with silica gel, a triple beam lab balance for determining silica gel drying column weight gains, 50 g Class P calibration weight for this balance, and equipment for leak checking samplers before sending them to the sampling location. High temperature fiberglass tape and permanent markers should be used to label the loaded sampler with its run number and substrate set identifier. Data is recorded on the run sheet bearing these numbers and all pre-run calculations are attached to this sheet. A hygrometer and thermometer are used to determine the relative humidity in the on-site laboratory. A portable barometer may be located in the lab and elevation connections used to obtain the pressure at sampling sites. This barometer can be carried into the control room and checked against the control room barometer (provided it reads room pressure and not the pressure at some point in the process).

In order to calculate stage  $D_{50S}$  on a Stokes diameter basis, one must determine the average particle density ( $\text{gm}/\text{cm}^3$ ). This value is determined from helium pycnometer measurements on screened hopper samples. The hopper ash is screened with a No. 60 Sieve (ASTM E 11 sieve Designation, 250  $\mu\text{m}$  openings) to remove rust, agglomerates, etc., which would not have been captured by the control device but may be found in hopper samples. This type of testing is performed by numerous commercial testing laboratories.

Calibration procedures are described in Section 5. Laboratory calibration equipment used includes a wet test meter for calibration of the dry gas meter and orifice and a reference dry gas meter to determine when recalibration (by wet test meter) is required. Other calibration equipment may be used either pre-test in the lab or on-site. These include a precision glass thermometer with ice water bath and hot plate for thermocouple/controller calibration, dial calipers as listed above for nozzle calibrations, mercury barometer, standard pitot or reference pitot, slant tube manometer for

magnehelic differential pressure meters, and Class S calibration weights for the analytical balance.

### 3 REAGENTS AND CONSUMABLES

Various reagents are used in connection with cascade impactor sampling. These include substrate materials and filters as well as any chemical used to prepare them, desiccants, water, ice, acetone and stopcock grease. The water is used for priming the condensers and the ice for chilling the condensers in an ice bath. If Method 5 glassware is used in place of the condenser and drying column, acetone-insoluble, heat-stable silicone grease (stopcock grease) may be needed to form an airtight seal at the ground ball and socket joints. Alternate designs which eliminate the ball and socket joints do not require the stopcock grease. Indicating type silica gel (6 to 16 mesh) may be used as a desiccant in the drying column and desiccators. Previously used silica gel may be rejuvenated by heating at 175°C (350°) for two hours. A change in color indicates that the desiccant has been depleted. Acetone is used for washing down the nozzles, etc. The wash is evaporated and weighed to determine the total amount of particulate present. Consequently the acetone should be reagent grade with no more than 0.0001% residue. Acetone should only be stored in glass bottles (or temporarily in polyethylene bottles) since metal containers can greatly increase the residue content. Acetone blanks are run prior to the field test and only acetone with low blank values (0.001%) may be used.

The filters and substrate material used depend on the sampling situations and the type of impactor to be used. High temperatures can prohibit the use of grease inserts. High flue gas sulfur levels can cause significant weight changes in the filter due to reactions with the flue gas constituents. For these reasons blank impactor runs are required as described in Section 4.3.2. In most cases only four to ten impactor runs will be made during a field test. When this is the case one can arrive on site with sufficient quantities of two or more types of substrates so that if a blank run shows unacceptable weight changes with, for example, greased substrates, preweighed quartz would be on hand for use. If numerous runs are to be performed and it is impractical to have prewashed substrates or multiple types, blanks should be run during the pretest site survey to select the substrate material to be used. Acid washing of fiberglass substrates to minimize reactions with SO<sub>2</sub> is described in Section 4.2.2.3 along with a detailed discussion of substrate options. Any filters used should be certified as 99.95% efficient on 3.0 um dioctyl phthalate smoke particles. This filter test is described in ASTM Standard Method D2986-71. Test data from the supplier's quality control program are sufficient for this purpose.

### 4 PROCEDURES

#### 4.1 PRE-TEST LABORATORY PREPARATION

Pre-test laboratory preparations include equipment maintenance, equipment calibration, and substrate preparation and weighing.

#### 4.1.1 EQUIPMENT MAINTENANCE

The right angle precollector and impactor do not require any special maintenance other than simple cleaning and ultrasonic cleaning of the impactor jet plates (to prevent any buildups that could change the hole sizes). All internal parts must be spotlessly clean before a run so that any particulate on the substrates can accurately be attributed to the stack gases. From time to time it may be necessary to use a lapping compound between threaded surfaces to repair rough threads and prevent gauling. Some impactors have silver plating on their threads to prevent gauling. Silver plating is highly recommended for temperatures above 425°F. The threads should be loose and smooth, not tight or rough. Teflon tape may be used to prevent gauling when the temperature is less than 425°F. It should be noted that some liquid base thread lubricants can contaminate the substrates and should be avoided. When needed, use them sparingly. The blank impactor run should reveal problems of this type. When nozzles are damaged they usually require repair by a machine shop. Frequently, this requires being bored out to a larger diameter.

The sampling train is a standard Method 5 train and is to be maintained as described in Method 5.

#### 4.1.2 SUBSTRATE MATERIALS AND PREPARATION.

Cascade impactors use lightweight inserts for the collection plate below each jet stage. These inserts must be lightweight to permit the detection of very small weight changes (0 to 15 mg) and must hold the captured particulate matter in place. As discussed in Section 3 (Deviations from Theory) particle bounce can present problems. Some aerosols are wet and sticky and can be satisfactorily collected with bare metal inserts, but such is not generally the case. Hence, most aerosols require the use of something to absorb the particle momentum and keep particles from bouncing to surfaces where they don't belong. Various substrate material options are available for this purpose. Certain impactor designs, however, exclude or make it difficult to use some of these options. The main options are bare metal, greased metal, polypropylene coated metal, fiberglass, and quartz. Bare metal is restricted to sticky aerosols that do not exhibit bounce problems.

##### 4.1.2.1 COATED METAL FOIL

Greased metal foils are generally the preferred substrate choices, except at higher temperatures. Felix, et al ii, (1977) tested 19 different greases for possible use at typical stack temperatures. Many were found to be unstable at stack temperatures. Some hardened and others flowed too freely. Only one was found to be sufficiently stable at 177°C (350°F), Apiezon H. This particular brand of grease is commonly used in gas chromatography (GC) and is available through several laboratory supply vendors. The manufacturer is James G. Biddle Co., Plymouth Meeting, PA 19462. The company offers a second version formulated for temperatures near ambient, Apiezon L (L for low temperature and H for high temperature). Apiezon H was found to be too hard a



coating at lower temperatures (125°C) but the L formulation worked well at some sources at these temperatures.

Other greases or polymers have been used successfully under conditions of flue gas composition and temperature which are hostile to Apiezon H. Specifically, low-molecular-weight amorphous polypropylenes have been found to perform well with little weight change in gases containing high levels of sulfur oxides. Unpublished results of research by J. D. McCain at Southern Research Institute showed that Hercules AFAX 800 and 500 (HL1) amorphous polypropylenes have suitable viscosities to be used, respectively, at ambient and stack (up to 165°C) temperatures. Another compound which has been found not to degrade at stack temperatures up to 230°C is Exxon 065 butyl rubber. An additional benefit of these polymers is that they contain sufficient low levels of trace metals to be used as collection surfaces for samples intended for elemental analysis by such techniques as neutron activation analysis (NAA).

It is probable that other greases or compounds may perform as well as those mentioned above for particular conditions. In general, any material is suitable if it has the consistency of a tacky fluid at the sampling temperature and if it does not show a significant change in weight or other physical properties due to interaction with the hot flue gases.

The greases are normally applied as suspensions or solutions of 10-20% grease in a solvent. Toluene is a suitable solvent for Apiezon H and L. Cyclohexane has been used for the polypropylene and butyl rubber polymers. The mixture is placed on the cut foil substrate with a brush medicine dropper, or sprayed onto the foil with an airbrush. Approximately the same amount of coating (same number of drops) should be applied to each substrate. This can be very significant in situations where a flue gas interaction is occurring. The reproducibility of any weight changes is discussed in Section 4.7.17, but different amounts of coating on different substrates can prevent weight change from being uniform. The coated foil is baked at 150°C (300°F) for 1 to 2 hours and then dried 12-14 hours over silica gel in a desiccator at ambient temperature prior to weighing. It is important to avoid an excess of grease. Too much grease, or one with too low a viscosity, causes "blow off" problems—the physical removal, spreading, or creep, of the grease off the impactor stage. The dry greased surface of the substrate should be tacky, but not slippery, with a film of thickness equal to or greater than the diameter of the particles which are to be captured. Typically, the amount of grease on a suitably coated substrate will be about 10 to 25 milligrams.

#### 4.1.2.2 FIBER MATS

Glass or quartz fiber mats are used routinely in some commercial impactors and in all impactors for sampling at temperatures above the limits of greases. In addition to providing a light-weight impaction surface, such fiber mats reduce reentrainment due to particle bounce. Fibrous substrates have different collection characteristics from those of flat surfaces, so calibrations performed with fiber mats must be used for reduction of data taken with fiber mat substrates.

Glass fiber mats and in some instances, quartz mats, cut to the required shape, can usually be obtained from the impactor manufacturer. Mats of other fibers can usually be cut to shape upon request to the manufacturer. In particular, quartz fiber mats may be preferable for substrates for use at higher temperatures or where sulfur oxides are a problem as mentioned below. The quartz mats must be handled carefully to avoid loss of fibers.

In hot gases containing sulfur oxides, glass fiber mats often exhibit anomalous gains in weight due to reaction with sulfur oxides and the formation of sulfates. After extensive laboratory and field experiments on a number of glass fiber mats (Felix, et al., 1977; Cushing, 1978; Peters and Adams, 1978), the only mats that have to date been found suitable for use as impactor substrates are Whatman 934AH (former Reeve Angel 934AH) and Schleicher and Schuell No. 30. Both are available from Whatman, Inc., 9 Brideswell Place, Clifton, NJ 07014. When these materials are treated with sulfuric acid by the procedure outlined below, gains in weight caused by reaction with flue gas constituents can be kept acceptably low. Glass fiber backup filters exhibit the same behavior and should be treated in the same manner.

In the studies mentioned above, quartz fibers were found to have negligible weight changes in the presence of sulfur oxides, but most pure quartz fiber mats were also found to be too fragile for use as substrates. Since the time of these studies, Pallflex 2500 QAST quartz fiber filters have been introduced. While still more fragile than glass fiber mats, these quartz mats have proven to be sufficiently strong for use as substrates for several impactors. As appears general for quartz fiber materials, 2500 QAST mats were found to exhibit low blank weight gains at stack conditions, even without the acid washing treatments recommended below for glass fiber mats.

#### 4.1.2.3 ACID WASHING FIBER MATS

1. The mats should be submerged in a 1:1 mixture (by volume) of distilled water and reagent-grade concentrated sulfuric acid at 100-115°C (210-240°F). Maintain the mixture at this temperature for 2 hours. This operation should be conducted in a fume hood using clean glassware and a temperature controlled laboratory hot plate. If the fiber mats need to be weighted down to keep them submerged in the acid bath, Teflon disks may be placed on the top and bottom of the stack and a glass or Teflon weight placed on top of this disk.
2. After removing the mats from the acid bath, they should be allowed to cool to room temperature and then be placed in a bath of distilled water and rinsed continuously with a water flow of 10-20 mL/min. until the pH value of the rinse water, after a few minutes in contact with the mats, is nearly the same as that of distilled water. The importance of thorough washing cannot be over-emphasized.

3. After rinsing in the distilled water, the mats should be rinsed in reagent-grade 2-propanol (isopropanol, isopropyl alcohol) by submerging them for several minutes. Repeat this step four or five times using fresh 2-propanol each time.
4. Allow the mats to drain and dry. After they are dry enough to handle, spread them out in a clean place to dry.
5. When the mats are dry to the touch, they should be baked in a laboratory oven at 100°C (212°F) for about 2 hours, to vaporize residual water and alcohol, then raise the oven temperature to 370°C (700°F) for 3 hours. This vaporizes any residual sulfuric acid. The mats may become discolored unless the water and alcohol are driven off prior to vaporizing sulfuric acid.
6. To verify that the acid has been removed, one can tear two mats into small pieces, immerse them in about 50 mL of distilled water, stir the water for about 10 minutes and measure the pH with a meter. If the pH is significantly lower than that of the distilled water, the remaining mats may be baked at 370°C (700°F) for several additional hours to remove any residual acid. The 370°C (700°F) temperature is necessary because of the high boiling point of sulfuric acid, 340°C (640°F).

#### 4.1.2.4 ON-SITE MAT CONDITIONING

Even after being washed with sulfuric acid, glass fiber mats have still shown anomalously high gains in weight in some process streams, particularly those at extremely high temperatures and those containing relatively large concentrations of sulfur oxides. If blank runs with acid-washed substrates reveal problems, they can be minimized by conditioning the glass fiber mats in the process gas stream prior to use. Place the mats, loosely packed, in a suitable container preceded by a filter; insert the container into the gas stream, and draw filtered flue gas through the container for 6-24 hours before the initial desiccation and weighing. Blanks should be run with these in-situ conditioned and washed glass fiber mats. These will be used to verify the magnitude and reproducibility of any remaining weight changes.

#### 4.1.3 BACKUP FILTERS

Backup filters are used on all impactors to collect the material that passes the last impactor stage. Binderless glass fiber filter mats are normally used for this purpose in all impactors, although the shape and size of the filter varies according to the impactor design.

Glass fiber backup filters have the same reactivity problems as glass fiber impaction substrates and may also require acid washing or conditioning. Quartz fiber filters should not require this treatment, and are available in many standard sizes. At temperatures below 150°C, Teflon fiber or membrane on fiber filters have also been found to perform well. Teflon inserts (washers) may be used to prevent the filter from sticking to the metal surfaces and a foil pouch is used to prevent the loss of particulate

collected on the fiber. In high temperature situations where Teflon is unacceptable, Kapton inserts may be substituted. A second filter is frequently used as a quality assurance check.

#### 4.1.4 WEIGHT RECORDS

A normal part of the pre-test laboratory preparations is to both prepare the substrates to be used during the test and then obtain their dry prerun weights. This weighing function may be performed on-site if desired but is generally performed before hand so that the on-site time can be more effectively utilized. Calibration procedures and control weights are used to insure that no errors are introduced by moving the weighing laboratory between weighings (pre and post). The post-run desiccation and weighing should be done on-site to avoid particulate losses from occurring during transport back to the home laboratory.

### 4.2 ON-SITE PROCEDURES

The following paragraphs describe the procedures that must be performed on-site in order to characterize particle size distribution of a stationary source using cascade impactors. Some of the functions may be performed during a pre-test site visit and some may be performed prior to the test in the home laboratory rather than on-site.

#### 4.2.1 PRELIMINARY PREPARATION

Manual, Table C-1 (Preliminary Survey for Particulate Sizing) and Table C-2 (Safety Checklist) list preliminary information that is needed prior to any field test. In situations where a pre-test site survey is performed, most of this information would be obtained at that time. The normal situation would not require that a pre-test site survey be conducted since most testing would be performed with a small 2 or 3 person crew at a familiar site. Most of the information in Table C-1 and Table C-2 could be obtained through dialogue with plant personnel and examination of previous compliance test reports. Any information not yet obtained should be gathered immediately upon arrival at the test site. Most of the missing information will be obtained during the initial inspection of the sampling site.

##### 4.2.1.1 TRAVERSING PROTOCOL

In order to obtain a representative measurement one must obtain samples at representative points across the duct (stack) at isokinetic rates. In the case of conventional total particulate testing (e.g., Methods 5 and 17), this is accomplished by dividing the duct into a large number of equal area segments (per Method 1) and obtaining an isokinetic sample at the centroid of each of these areas. Isokinetic sampling is achieved by selecting a nozzle which is appropriate for the combination of the nominal flow rate at which the sampler is intended to operate and the average duct velocity. Compensation for duct velocity variations is then achieved by adjusting the sampling rate. This procedure cannot be used with the inertial particle classifiers

specified in this method because changes in sampling rates result in shifts in the characteristic diameter(s) of the size fractions.

With a fixed flow rate sampler the following procedure is recommended: establish anisokinetic limits and divide the sample plane (Method 1 Traverse points) into multiple regions such that all points within a given region may be sampled at a fixed flowrate with a single nozzle and satisfy the anisokinetic limits. Separate runs are then performed for each region. The runs are averaged using a weighting proportional to the total volumetric flow of each region, this average synthesizes a complete traverse. Method 1 procedures are used to define the complete traverse and Method 2 procedures are used to determine the velocity at each point.

The recommended isokinetic error limit for the above procedure is that each point sampled by an impactor should have a point velocity that is within +20% of the impactor inlet velocity. Each of the traverse points which would be used in a standard Method 5 run should be sampled; thus if the ratio of the minimum velocity to the maximum velocity is greater than 1.5, multiple impactor runs are required. In this case, two or more regions would be selected such that for each region the velocity at every point within the region satisfies the 20% requirement.

Thus for any point  $i$  within a given region, the velocity at that point ( $u_i$ ) meets the criteria  $.8V < u_i < 1.2v$  where  $V$  is the sampling velocity into the impactor nozzle (fixed by the choice of the Nozzle Diameter and Impactor Flow Rate).

The following is a suggested technique for selecting the regions and respective sampling velocities when more than one region is required (i.e.,  $u_{max}/u_{min} > 1.5$ ):

Order the point velocities from the lowest ( $u_{min}$ ) to the highest ( $u_{max}$ ) then determine the 20% limits associated with each of the regions as follows:

For Region A:

$$u_{min} = u_{Amin} = 0.8 v_A$$

$$\text{thus } v_A = 1.25 u_{min}$$

$$\text{and } u_{Amax} < 1.2 v_A$$

For Region B

$$u_{max} = u_{Bmax} = 1.2 v_B$$

$$\text{thus: } v_B = 0.833 u_{max}$$

$$u_{Bmin} > 0.8 v_B$$

If  $u_{Amax} < u_{Bmin}$  it may be necessary to assign a third Region (Region C) since there are some point velocities which are not covered by Regions A and B. It should be noted that it is very possible to have a skewed velocity distribution where there are two tight groupings of low velocity points and high velocity points such that although  $u_{Amax}$  is less than  $u_{Bmin}$ , all the points are either less than  $u_{Amax}$  (Region A) or greater than  $u_{Bmin}$  (Region B). If there are points that lie between these two limits

$$u_{Amax} < u_i < u_{Bmin}$$

then a third region, Region C, (or possibly more than one additional region) would be required. Denote these points as  $u_i$  and repeat our previous approach as follows:

For Region C:

$$u'_{min} = u_{Cmin} = 0.8 v_C$$

$$\text{thus } v_C = 1.25 u'_{min}$$

$$\text{and } u_{Cmax} < 1.2 v_C$$

If there are still some points remaining which do not fall within Region C then additional Regions would be called for as follows:

$$u'_{max} = u_{Dmax} = 1.2 v_D$$

$$\text{thus } v_D = 0.833 u'_{max}$$

$$u_{Dmin} > 0.8 v_D$$

In the unlikely event that additional points remained then yet more regions could be constructed by repeating the process above using “ $u$ ” to designate all remaining points. Two regions will usually be sufficient. In some cases additional regions may be required. These cases would generally be situations where major flow obstructions existed close to the sampling ports.

If a 10% anisokinetic limit is desired rather than the 20% limit used above, then one may substitute  $u_{min} = u_{Amin} = 0.9 v_A$  and  $u_{Amax} = 1.1 v_A$ , etc.

To be rigorous, one should adjust the dwell time at each point within a region so that the sample time at each point is velocity weighted and rounded to the nearest half minute. Although this is valid in that emissions factors are velocity dependent, the use of variable dwell times at each sample point can cause confusion on the part of the operator. As total emission rates are normally based on Method 5/17 Runs, which are isokinetic, the suggested procedure is that equal dwell times be used.

It should be noted that use of different nozzles with the same impactor flow rate will produce different sampling velocities ( $V$ ). The actual sampling velocity will depend on the choice of nozzle diameter and impactor flow rate as velocity will depend on the choice of nozzle diameter and impactor flow rate as described in Section 4.2.1.6. It may be necessary to reassign points from one Region to another if it is not possible to obtain  $V_A$ , etc. (as calculated above) in light of the constraints of Section 4.2.1.6.

#### 4.2.1.2 NOZZLE CHOICE, FLOW RATE, AND IMPACTOR STAGES

The general process is as follows: (1) measure/calculate the flue gas temperature, pressure, moisture, mean molecular weight, and required sampling velocity for a given traverse region then estimate the mass loading; (2) make an initial guess at the impactor flow rate that will give a reasonable sample time to collect weighable quantities on each stage; (3) select a nozzle and adjust the initial guess at the impactor flow rate so as to obtain the required sampling velocity for this traverse region; and (4) select stages that will give the desired stage cuts at this flow rate without resulting in particle bounce ( $VD_{50}$  product guidelines) or unacceptably low Reynold's numbers. The following paragraphs elaborate on these four steps. Steps 3 and 4 must be repeated for each of the traverse regions since different regions may require different flow rates, nozzles, and/or stage configurations. The following paragraphs illustrate the selection process for region A.

##### 4.2.1.2.1 PRELIMINARY CALCULATIONS

Section 6 discusses the calculation of the flue gas temperature, pressure, moisture, mean molecular weight, and required sampling velocity for traverse region A. Plant personnel are generally able to provide approximate particulate concentration information (mass loading, gr/acf). If this information is not available, it may be necessary to run the in-stack filter to obtain a "good guess" at the particulate concentration so that  $t_{50\text{mg}}$  may be determined as described below.

##### 4.2.1.2.2 TIME FOR 50 mg

An initial guess for the impactor flow rate is made by calculating the time to collect a total sample of 50 mg particulate ( $t_{50\text{mg}}$ ). Equation 30 may be used to calculate this value for various flow rates or the nomogram shown in Figure 2 may be used to estimate  $t_{50\text{mg}}$  as described in Section 6.1.6.1. In this manner a flow rate may be found that will result in an acceptable run time as described in Section 6.1.6.1.

Note: It may be necessary to select a different flow rate and repeat steps 3 and 4 if the criteria of Step 4 are not satisfied.

##### 4.2.1.2.3 NOZZLE CHOICE AND FLOW RATE

In Step 2 we determined the impactor flow rate which would produce an acceptable run time ( $t_{50mg}$ ). We may now use Equation 32 to calculate the ideal nozzle diameter that would yield the required sampling velocity ( $V_A$ ) for this traverse region when the sampler is operated at the flow rate determined in Step 2 above. From the set of available nozzles one would now select the real nozzle ( $D_{nA}$ ) closest to this ideal size and use Equation 12 to calculate the corrected flow rate ( $Q_A$ ) for this real nozzle. This flow rate is isokinetic to  $v_A$ , the mean velocity of Region A.

Figure 3, Nomograph for Selecting Nozzles for Isokinetic Sampling, is used to determine this corrected flow rate.

Note: In inlet sampling situations the nozzle must be very small to permit isokinetic sampling at low impactor flow rates. The minimum useful nozzle size is 1.4 mm (0.0550 inches, wire guage drill size No. 54) because smaller nozzles tend to plug during the run. The 1.0 mm nozzle size shown on Figure 3 is for information purposes only and is not recommended for normal use. If feasible, nozzle sizes should be 1/8 inch or larger.

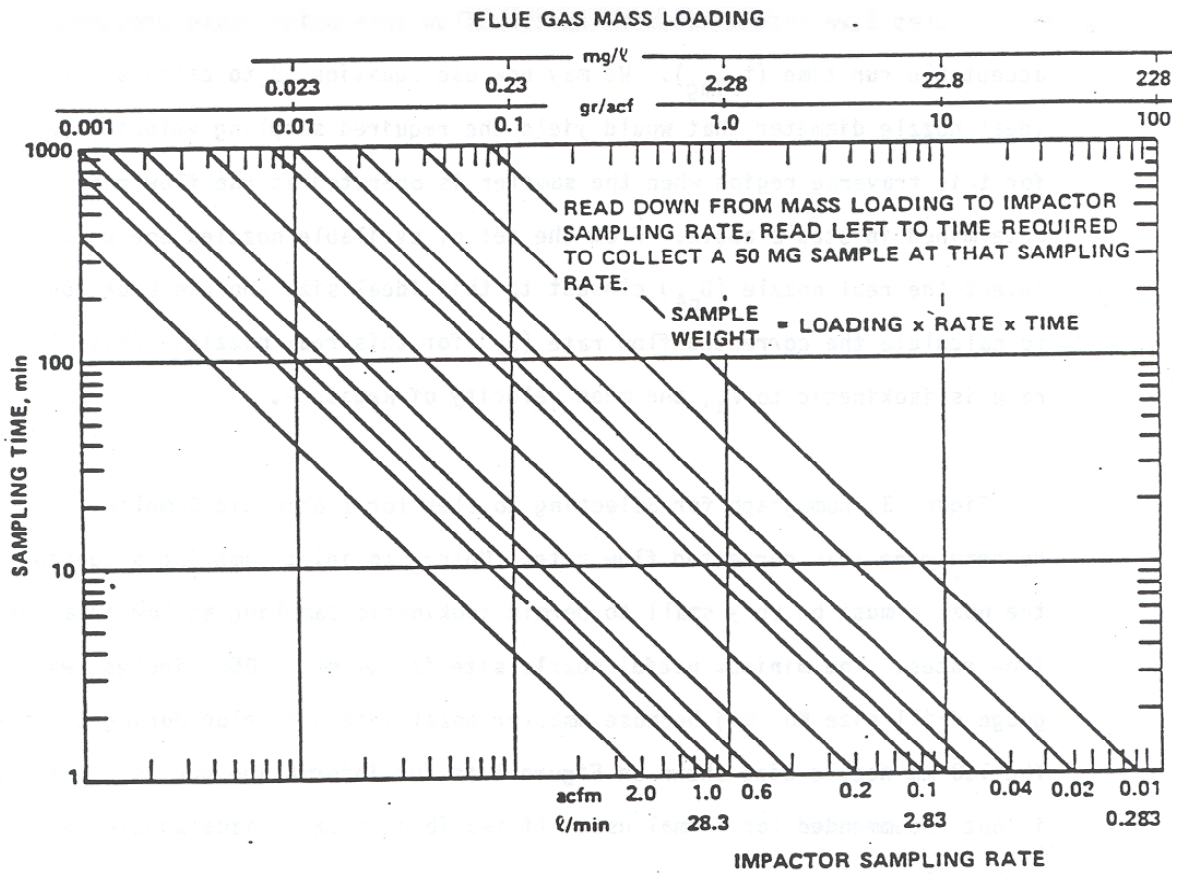
#### 4.2.1.2.4 STAGE CONFIGURATION

Using the corrected flow rate ( $Q_A$ ) determined in Step 3, one would now select the stages which would give the desired size cuts without resulting in (1) particulate bounce or (2) unacceptably low Reynold's numbers.

Note: It may be necessary to choose a different flow rate and repeat Step 3 if the criteria are not satisfied. If the design of the impactor used does not permit stages to be selected/deleted then one must continue to try different flow rates until one is found for which all the stages satisfy the two criteria given above. In such cases, one may be forced to compromise on either the desired stage cuts or to tolerate undesirably short or long run times. Data is suspect and may need to be rejected if any one of the stages are operated in a bounce mode or at very low Reynold's numbers. the preferred impactor design is one that permits the selection of stages to optimize the configuration used.

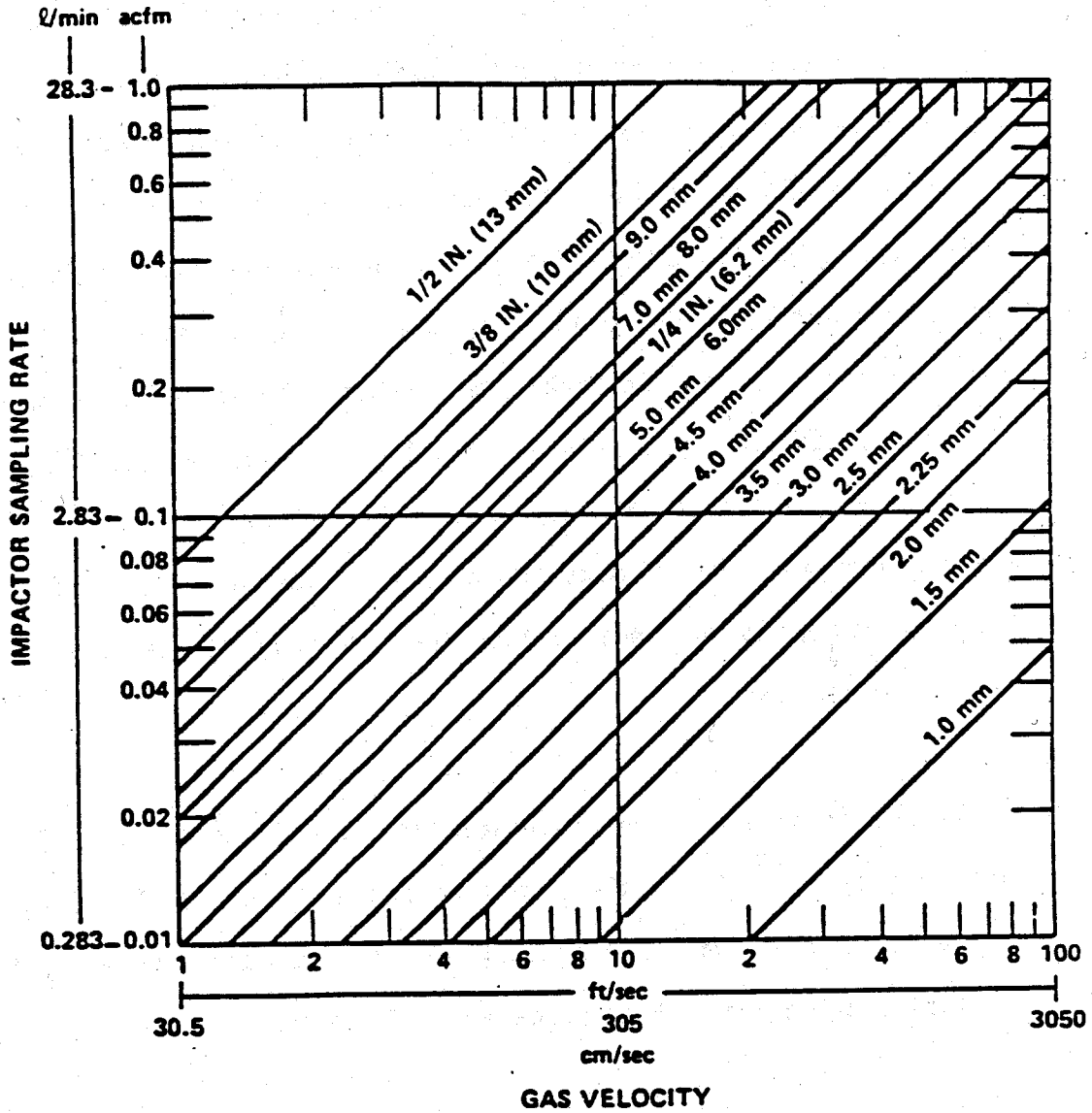


FIGURE 2



*Nomograph for determining sampling time (50 mg sample).*

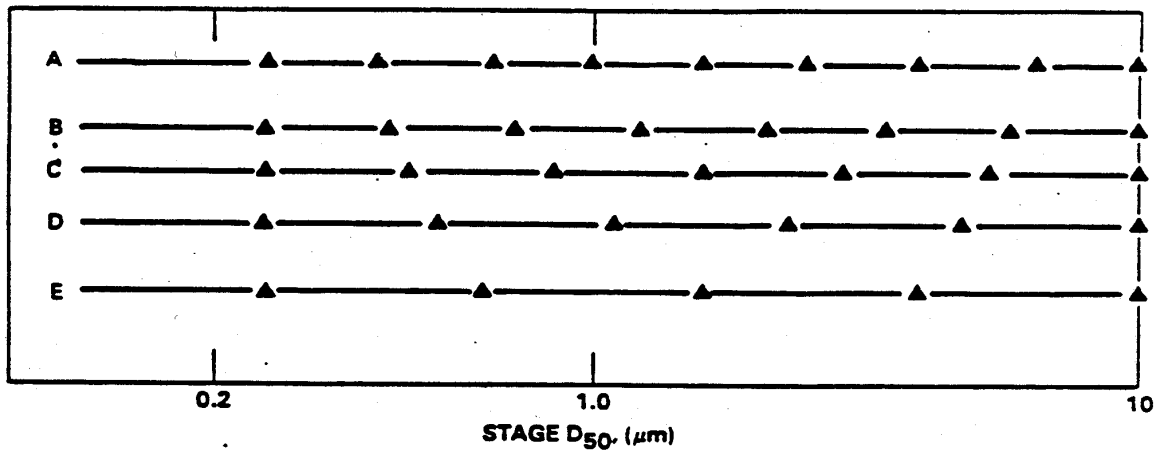
FIGURE 3



*Nomograph for selecting nozzles for isokinetic sampling.*

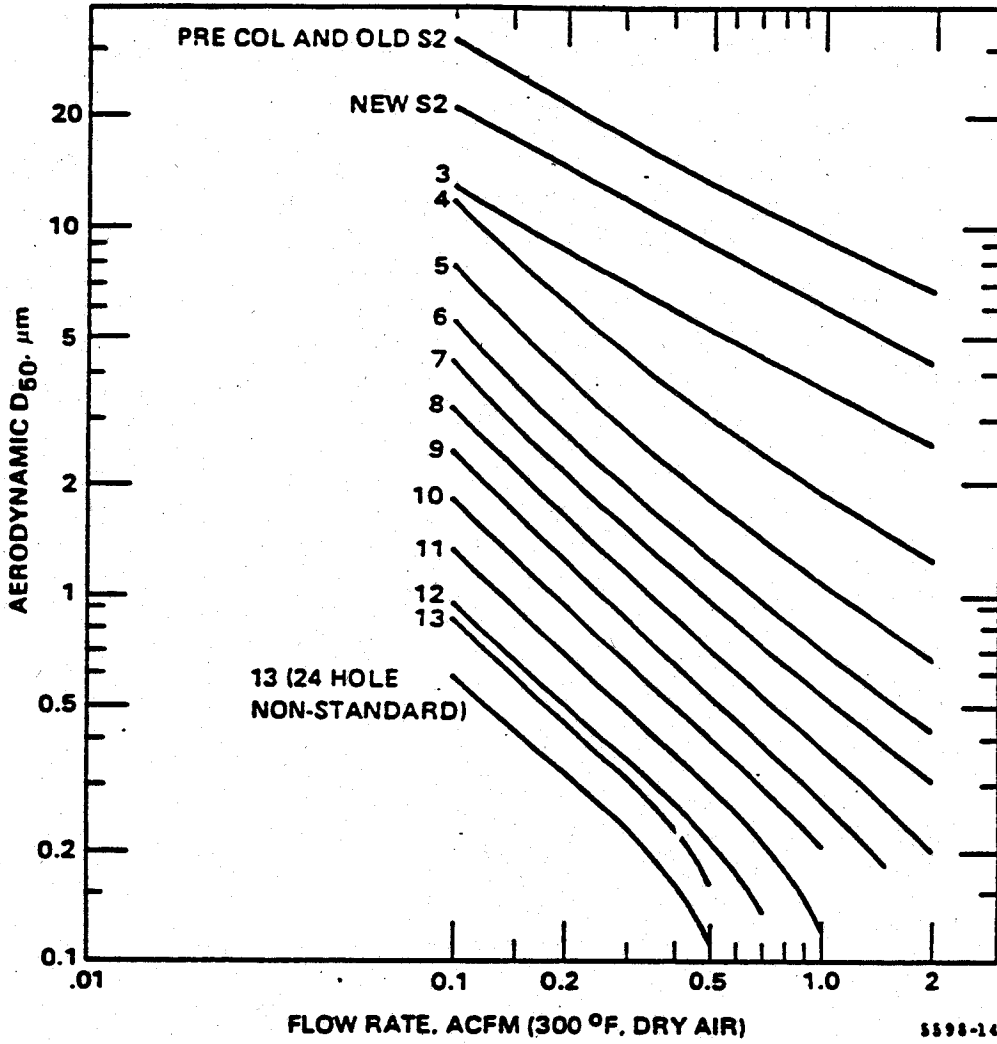
FIGURE 4

NUMBER OF CUTS	:	9	8	7	6	5
RATIO OF CUTS	:	1.585	1.694	1.849	2.089	2.518
CONSTANT $\Delta \log D$	:	0.200	0.229	0.267	0.320	0.401
PRECOLLECTOR $D_{50} (\mu m)$	$\geq 10$	$\geq 10$	$\geq 10$	$\geq 10$	$\geq 10$	
FIRST STAGE $D_{50} (\mu m)$	:	6.3	5.9	5.4	4.8	4.0
SECOND STAGE $D_{50} (\mu m)$	:	4.0	3.5	2.9	2.3	1.6
THIRD STAGE $D_{50} (\mu m)$	:	2.5	2.1	1.6	1.1	.63
FOURTH STAGE $D_{50} (\mu m)$	:	1.6	1.22	.85	.52	.25
FIFTH STAGE $D_{50} (\mu m)$	:	1.0	.72	.46	.25	—
SIXTH STAGE $D_{50} (\mu m)$	:	.63	.42	.25	—	—
SEVENTH STAGE $D_{50} (\mu m)$	:	.40	.25	—	—	—
EIGHTH STAGE $D_{50} (\mu m)$	:	.25	—	—	—	—
PLOT DESIGNATION	:	A	B	C	D	E



*Desired size cuts range of interest: 0.25  $\mu m$  to 10  $\mu m$ .*

FIGURE 5



*Pollution Control System Mark V Impactor stage cuts (at 300 °F, 29.00 Hg, dry air) for multiple flow rates.*

The desired size range and resolution is 0.25 to 10  $\mu\text{m}$  with 5 to 8 cuts evenly spaced on a log scale (constant ratio of 2.52 to 1.69) as shown in Figure 4. Thus we want the precollector to cut at or above about 10  $\mu\text{m}$  and the last stage to cut at or below about 0.25  $\mu\text{m}$ .

It should be noted that any stages having a  $D_{50}$  comparable to or larger than the  $D_{50}$  of the precollector will have little if any particulate catch and these catches will have no significance as sizing data. If possible, such stages should not be used. For data analysis purposes, (if they must be included) the weights of the material collected on such stages should be combined with the catch of the first stage having a  $D_{50}$  smaller than that of the precollector; and the intermediate stages should be omitted in the  $D_{50}$  calculations, etc.

One must verify that each stage selected meets the two criteria given below for the specified flowrate ( $Q_A$ ).

Note: "V" has been previously used to represent the stack gas velocity. In the following paragraphs, we are using " $V_i$ " to represent the jet velocity for any one of the jets on impactor stage i.

The criteria are (1)  $VD_{50}$  product be less than a critical value, CV, to prevent bounce and scouring and (2) the jet Reynolds Number, Re be greater than 50. These two considerations compete against each other. For a given jet size as the flow rate is increased the  $D_{50}$  decreases, but the Re and the  $VD_{50}$  increase. As the velocity is decreased, one can stay below the  $VD_{50}$  limits but the run time increases and Re may approach values where the impactor calibration data ceases to be valid. The  $VD_{50}$  product guideline, CV, depends on the type of substrate material used, and has the following values: Bare Metal: 5  $\mu\text{m}\cdot\text{m/s}$ , Fiberglass: 15  $\mu\text{m}\cdot\text{m/s}$ , and Grease: 25  $\mu\text{m}\cdot\text{m/s}$ . The desired Re value is greater than 100. It is possible to operate at lower values, but the desired range is at least 100. If a run results in Re values of 50 or less it should be considered suspect because the theory has not been proven in this regime. The other considerations in selecting a flow rate are the desired maximum and minimum  $D_{50}$ 's. The higher the flow rate the smaller the  $D_{50}$  for the same stage. This is illustrated for the Pollution Control Systems Mark V impactor (U of W) in Figure 5 for the stated conditions of temperature, and flue gas composition. Equations for calculating stage  $D_{50}$ 's are given in Section 6.1.19 and Computer Programs for performing these calculations are described in Manual, Appendix A.

#### 4.2.1.6 RUN TIME

As mentioned above, Figure 2 is a nomograph for determining the sample time to collect 50 mg ( $t_{50\text{mg}}$ ) of particulate given the Flue Gas Mass Loading and sample flow rate. The equations used to calculate run time are given in Section 6.1.6.1. Figure 2 should be used to make an initial guess at the run time for the initial impactor run. Adjustments for subsequent runs are then made after examining the substrates from the initial run.

To use Figure 2, one must make an initial guess at the flue gas mass loading ( $G_A$ , gr/acf) then read down to the appropriate impactor sampling rate curve (2 ACFM to 0.01 ACFM). Reading to the left from the intersection of the mass loading and sampling flow rate one will find the time required to collect a 50 mg total sample (sum of all the stage weights plus filter). The 50 mg total sample is a rule of thumb, the actual constraints are that no stage with the exception of the filter or precollector should collect more than 15 mg. At the outlet from a high efficiency control device, long run times may be unavoidable. Two hour outlet samples are desirable but six hour run times are common, and even longer runs are sometimes required. For inlet situations the concentration is typically very high and run times generally need to be very short to prevent overloading. The recommended minimum run time is 90 sec. If possible run times should be at least three minutes.

#### 4.2.2 BLANK IMPACTOR RUN

After an initial selection is made of sampling flow rate, stage configuration and nozzle diameter, two impactors are assembled as described in configuration and nozzle diameter, two impactors are assembled as described in Section 2 with the selected components. These will be the blank run and initial run. For simplicity, both the blank run and the initial run are usually single point runs rather than following the traversing protocol. If large concentration gradients are expected, the initial run should traverse the entire area to be sampled.

After the selected orifice has been installed on the dry gas meter the initial setup leak check of the meter box back half should be performed as described in Section 4.3.4.4 (Leak Check Procedures). The initial check does not need to be repeated unless the meter box is moved or a different orifice is installed.

It has been shown that some substrate materials can change weight by simple exposure to particulate free stack gases. When such substrate-flue gas interactions occur, it is important to determine the magnitude and reproducibility of these extraneous

weight changes so that the true particulate loadings can be determined. The problem usually relates to sulfur oxides in the flue gas and the chemistry of a particular type of substrate material being used. When greased metal foils are used as substrates, temperature can also be a problem. Proper selection of substrate material and, in some cases in-situ conditioning of the material, can eliminate or minimize the problem. Section 4.2.2 gives guidance for the judicious selection of substrate materials for various sampling situations. As a quality control check the precollector is replaced by a filter holder containing one or more unweighed filters and attached to the inlet of a impactor loaded with preweighed substrates of the selected material (greased metal, fiberglass, etc.). This configuration is referred to as a "blank" impactor. This assembly is then inserted in the stack and, after warmup, stack gas is pulled through the impactor at approximately the same flow rate and for the same duration as a real run. The objective is to expose the substrates to flue gas under the same conditions as those of

the real runs. With the filter preceding the impactor, all the particulate should have been removed so that any weight changes can be ascribed to the flue-gas substrate interactions. The blank weight change for any given substrate should not exceed 0.25 mg or 10% of the stage catch of the most lightly loaded substrate in the real runs, whichever figure is smaller. The impactor filter blank weight change should not exceed 0.25 mg. Larger blank weight changes can be tolerated if they are reproducible. An average change of 1.5 mg which is reproducible to  $\pm 0.1$  mg is preferable to an average change of 0.1 mg with a range of  $\pm 0.25$  mg as corrections can be applied if the changes are reproducible. If these limits are exceeded, alternative substrate materials should be tested until one is found which does satisfy the above criteria.

If no substrate material appears to be satisfactory, one last technique is to use in-situ conditioning as discussed in Section 4.2.2.4. If in-situ conditioned substrates are used, a blank must still be run to verify that weight changes are acceptable.

It should be noted that the precollector substrate is not included in the blank run. If the same substrate coating material is used on the both the precollector substrate and the impactor collection plate substrates, the same correction factor may be used for both if approximately the same amount of coating material was applied to both surfaces. Frequently, the precollector catch is very large and the collection factor is less than 1% of the total catch. In cases where the catch is low and the correction factor is significant, one may choose to scale the correction factor to the relative amount of coating material used on the two different surfaces or to construct special hardware that would permit the precollector to be included in the blank run.

Some precollectors permit the optional use of a fiberglass (or quartz) insert. If such inserts are used and loadings are low it may be desirable to construct the special hardware mentioned above. If the filter is constructed of the same material, one can obtain an estimate of any weight change by scaling the filter correction factor. Where the change seems to be significant, one should use coated foil inserts in the precollector rather than fiberglass inserts.

In situations where testing has been performed at similar sampling sites, experience will aid one in the substrate selection process. In other situations, one must run numerous blanks until an acceptable substrate material is found. Sometimes this is done during a pretest site or the crew may carry sufficient quantities of substrates of multiple kinds of material so that when the blank run shows a given material to be acceptable, testing can proceed without delay. If the test program is complex and involves a large number of people, it will usually pay to run blanks well beforehand to avoid lengthy delays should problems with substrates be found.

#### 4.2.3 INITIAL IMPACTOR RUN

The initial impactor run is used to gather information that can be used to adjust the sampling time for the subsequent runs. The initial run itself is seldom useful as data,

often being run only half as long as the rest of the runs. For this reason, it is often referred to as an explanatory run or “trash” run. It is usually a single point run rather than a full traverse and is normally run concurrently with the blank run. If the blank run indicates that a different substrate material must be used, it is at the discretion of the operator to run a second “trash” run concurrently with the second blank or run only the second blank. The normal case would be to assume the second choice of substrate material will prove to be acceptable and use the results of the initial run to adjust the run time so that this run (with) the new material) will provide acceptable data. If this second trash run is traversed and is deemed acceptable (examination shows that minimum/maximum stage loadings were obtained, scouring and bounce did not occur, etc.) then it may be counted as acceptable data. Each successive run is adjusted based on information gained from the previous runs. For a run to be counted as data, it must satisfy all the criteria listed in Section 7.1.2.

#### 4.3.4 SAMPLING RUNS

After making preliminary determinations and completing the blank impactor run and initial impactor run as described above, the individual sampling runs for data purposes may be made. The following paragraphs detail this process. Note: At this time all ports should have been opened, cleaned, and any needed port adapters installed.

##### 4.3.4.1 PRELIMINARY CALCULATIONS

Once decisions have been made about stage configuration, nozzle selection, and sampling flow rate, it becomes necessary to calculate the target  $\Delta H$  needed to obtain the desired sampling flow rate at the given set of stack conditions. This calculation is the same as that used for Method 5 sampling except that it is not necessary to generate the table of  $\Delta H$  vs.  $P_{pto}$  used to maintain isokinetic sampling. Once the run is started, the flow rate is not changed. As explained earlier, changing the flow rate changes the stage  $D_{50}$ 's. For this reason, a constant  $\Delta H$  setting is maintained throughout the entire run. The only flow adjustments made are those necessary to compensate for the filter loading. The traversing protocol described in Section 4.2.1.1 may be used to select a subset of the Method 1 traverse points such that the constant flow rate is always  $\pm 20\%$  of isokinetic for each point sampled. Multiple runs may be needed (each at a different flow rate or with a different nozzle) in order to traverse the full stack.

##### 4.2.4.2 IMPACTOR PREPARATION

Onsite laboratory preparation of the impactor includes loading the impactor with the selected jet plates and with preweighed, numbered substrates (same material as used with the blank impactor run), loading the precollector, attaching the calibrated nozzle, and attaching the precollector to the impactor, then leak testing the impactor/precollector combination. This leak test is optional because the mandatory QA postrun leak test will show if leaks have occurred and will either accept or reject the run as valid with respect to leaks. The purpose of this quality control laboratory leak test is to catch and correct any leaks (missing o-rings, loose fittings, etc.) before the run is



made. For this reason, a simple quick untimed procedure may be used. Once the impactor and precollector are loaded they are labeled with the run code (run identification number) shown on the run sheet. All data related to this run are recorded on the run sheet with the exception of the weight records. The substrate weight records are maintained in a separate log book that never leaves the on-site laboratory. Section 4.2.4.5 outlines the instructions for preparing the run sheet (shown in Figures 6 and 7). The velocity traverses are recorded on Method 2 Velocity Traverse Forms and are maintained separately from the run sheets. The following paragraphs describe the procedures for loading the impactor.

Before loading the substrates in the impactors, the impactor and precollector parts should be inspected to ensure that they are free of loose dirt, lubricants, or liquids. An ultrasonic cleaner is useful for removing contamination from small crevices (e.g. the inside of an Andersen impactor o-ring and the small jet holes of the last stages of the impactor). The jets of each impactor stage should be inspected by holding the plate between a light and the eye using a 10 x ocular. Metal gaskets should be checked for warpage or nicks and pliable gaskets checked for hardening, cracking, tears, slits, or imbedded dirt which could cause leaks. If there is any doubt about a gasket it should be replaced. The nozzle should be clean and the edges sharp and free of nicks.

During loading, handle the precollector, impactor, and nozzles with clean fingers and the substrates with tweezers or clean fingers by the edges. Make a final inspection of the substrates during loading. The substrates should have been inspected prior to the prerun weighings but this is a second check. If a substrate must be replaced, the replacement should be pulled from an "extra" set and the weight records and the run sheet annotated accordingly.

Where mating threads are both stainless steel, chrome, or silver plating of one or both mating surfaces will greatly reduce the potential for galling. Teflon thread sealant tape can be used on any threads that are not otherwise protected. Antiseize compounds should be used sparingly or not at all because of the possibility of contaminating the substrates.

After the nozzle, precollector, and impactor have been assembled they should be checked for leaks as mentioned above. Leaks at this point in the procedure can be easily found and corrected. Checking the pressure drop across the assembly for various flows of filtered air against predetermined values will indicate deviations from the norm resulting from both external and internal leaks and plugged jets.

When the impactor has been loaded and leak checked and the target H value calculated according to the traversing protocol, the sampler, run sheet, and preweighed drying column are ready to be carried to the sampling area. Section 4.2.4 provides a step-by-step guide to the preparation and operation of a sampling run. At this point, items L1 through L15 of Section 4.2.4.5.1 have been completed.

The following example illustrates the Pollution Control Systems (University of Washington) Mark III impactor which might be used. The case illustrated in Figures 8 and 9 is substrate set number I23 ("I" for impactor). The substrate set numbering code permits any set to be loaded into any impactor configuration (inlet or outlet). The designation of sampler hardware description and assignment is made on the run sheet, not in the substrate set coding.



FIGURE 6 Run Sheet - Lab Side.

LAB LOAD/UNLOAD SHEET FOR UNIVERSITY OF WASHINGTON IMPACTOR (SIX JET PLATES)

RUN CODE <p style="text-align: center;">L1</p>	PERSON UNLOADING IMPACTOR AND DATE UNLOADED <p style="text-align: center;">U4</p>
SUBSTRATE SET IDENTIFICATION NO. <p style="text-align: center;">L2</p>	NOTE YOUR OBSERVATIONS ON THE APPEARANCE OF EACH STAGE, SUBSTRATE, OR CYCLONE UPON DISASSEMBLY <p style="text-align: center;">U5</p>
PERSON LOADING IMPACTOR AND DATE LOADED <p style="text-align: center;">L3</p>	PRECUTTER 1 P <p style="text-align: center;">U5</p>
<ul style="list-style-type: none"> <li>• LOAD IMPACTOR</li> <li>• MARK SHELL AND PRECOLLECTOR WITH RUN CODE</li> <li>• LEAK TEST</li> </ul>	STAGE ZERO (DISK) 1 D <p style="text-align: center;">U5</p>
UNIVERSITY OF WASHINGTON MARK V IMPACTOR SHELL ID NO. _____ L4 JET PLATE SET ID NO. _____ STAGE CONFIGURATION _____ PRECOLLECTOR ID NO. _____ NOZZLE ID NO. _____ NOZZLE DIAMETER _____ (INCHES)	STAGE ONE (FIRST PLATE, NO. _____ L5A ) 1 -1 <p style="text-align: center;">U5</p>
LAB LEAK CHECK (60 SEC PRESSURE CHANGE) CHECK UNDER VACUUM (-8 IN. Hg) WITH PRECOLLECTOR: L6 INITIAL _____ (IN. Hg) FINAL _____ (IN. Hg) WITHOUT PRECOLLECTOR (ONLY IF LEAKS FOUND ABOVE) INITIAL _____ (IN. Hg) FINAL _____ (IN. Hg)	STAGE TWO (SECOND PLATE, NO. _____ ) 1 -2 <p style="text-align: center;">U5</p>
NOTES AND OBSERVATIONS <p style="text-align: center;">U3</p>	STAGE THREE (THIRD PLATE, NO. _____ ) 1 -3 <p style="text-align: center;">U5</p>
	STAGE FOUR (FOURTH PLATE, NO. _____ ) 1 -4 <p style="text-align: center;">U5</p>
	STAGE FIVE (FIFTH PLATE, NO. _____ ) 1 -5 <p style="text-align: center;">U5</p>
	STAGE SIX (SIXTH PLATE, NO. _____ ) 1 -6 <p style="text-align: center;">U5</p>
	BLANK OR BEHIND DISK (CIRCLE ONE) 1 -BX <p style="text-align: center;">U5 L5B</p>
	BACK UP FILTER 1 -F <p style="text-align: center;">U5</p>

FIGURE 7 Run Sheet - Run Side.

L7  
REAL BLANK

RUN CODE L8		DATE 1		DIFFERENTIAL STACK PRESSURE 2 (IN H <sub>2</sub> O)					
CONTROL BOX ID L9		START TIME 11		AMBIENT PRESSURE (LAB BAROMETER) 3 (IN Hg)					
GAS METER ID L10		END TIME 28		AMBIENT TEMPERATURE 4 (F)					
THE CALCULATED TARGET AM VALUES REQUIRES THE OPERATOR TO USE		SAMPLING DURATION (MIN) 12		-60 SEC LEAK TEST- PRE HOT A. 16 IN Hg W/SAMPLER 5 FT <sup>3</sup>					
ORIFICE ID L11		GAS METER-START 13 (FT <sup>3</sup> )		B. 8 IN Hg W/SAMPLER FT <sup>3</sup>					
SAMPLING ASSIGNMENT INLET, OUTLET, OTHER: L12		GAS METER-FINISH 29 (FT <sup>3</sup> )		C. 16 IN Hg W/O SAMPLER FT <sup>3</sup> POST HOT 30					
TARGET JM L13		TOTAL VOLUME BY GAS METER (ACF) 06		NOTE: RELEASE VACUUM AT NOZZLE TO AVOID RUPTURING FILTER. PASS 5 S.O.2 FT <sup>3</sup> FOR A OR B OR C VISUAL CHECK OF NOZZLE <input type="checkbox"/>					
	RUN TIME (MIN)	PORT NO. TRAVERSE POINT	GAS METER READING	GAS METER TEMP. (F)	FLUE GAS TEMP. (F)	19 ORIFICE JM IN. H <sub>2</sub> O	PUMP VACUUM IN Hg	PROBE TEMP. (F)	
	14	15	16	17	18			20	
1	↓	21	22	23	24	25	26	27	
2	↓								
3	↓								
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18									
19									
20									
21									
22									
23									
24									
25									
26									
27									
28									
29									
30									
POST TEST CALCULATIONS									
	07	TOTAL	08						
		AVG.	09	010	011	012			
-WATER- CONDENSER ID NO. 6 CONDENSER H <sub>2</sub> O CATCH 31 DRYING COLUMN WEIGHT CHANGE ID NO. L14 INITIAL WT. L15 (gm) FINAL WT. U1 (gm) (1 gm = 1 ml) H <sub>2</sub> O GAIN U1 (ml) TOTAL VOLUME H <sub>2</sub> O U2 (ml)									
NOTES AND OBSERVATIONS 32									
7 SAMPLING LOCATION INLET OUTLET IN THE SPACE BELOW GIVE THE UNIT, CHAMBER, DUCT, PANTLEG, ETC. WHERE THE SAMPLER WAS RUN PORT NUMBERS: SAMPLER ORIENTATION (CIRCLE ONE) HORIZONTAL TOP ENTRY VERTICAL 8 W/ TURN AROUND W/O TURN AROUND BOTTOM ENTRY VERTICAL OTHER									
OPERATORS 9									

Figure 8

Example of a completed Run Sheet - Lab Side.

<p>RUN CODE <b>SAMPLE CALC</b></p>	<p>PERSON UNLOADING IMPACTOR AND DATE UNLOADED <b>SSD 4-21-84</b></p>
<p>SUBSTRATE SET IDENTIFICATION NO. <b>I 23</b></p>	<p>NOTE YOUR OBSERVATIONS ON THE APPEARANCE OF EACH STAGE, SUBSTRATE, OR CYCLONE UPON DISASSEMBLY</p>
<p>PERSON LOADING IMPACTOR AND DATE LOADED <b>SSD 4-20-84</b></p>	<p>PRECUTTER <b>23 GOOD LOADING, NO SIGN OF NOZZLE SCRAPINGS IN CATCH.</b></p>
<p> <input checked="" type="checkbox"/> LOAD IMPACTOR  <input checked="" type="checkbox"/> MARK SHELL AND PRECOLLECTOR WITH RUN CODE  <input checked="" type="checkbox"/> LEAK TEST         </p>	<p>STAGE ZERO (DISK) <b>23 LIGHT LOADING</b></p>
<p>UNIVERSITY OF WASHINGTON MARK III          SHELL ID NO. <b>III Z MARK III</b>          JET PLATE SET ID NO. <b>III Z</b>          STAGE CONFIGURATION <b>P, 2, 3, 4, 5, 6, 7, B, F, BF</b>          PRECOLLECTOR ID NO. <b>Z</b>          NOZZLE ID NO. <b>Z-3</b>          NOZZLE DIAMETER <b>3/16 (0.188)</b> (INCHES)       </p>	<p>STAGE ONE (FIRST PLATE, NO <b>2 (OLD)</b>) <b>23 GOOD PEAKS, NO INDICATION OF BOUNCE FROM SOLID DISK</b></p>
<p>LAB LEAK CHECK (90 SEC PRESSURE CHANGE) CHECK UNDER VACUUM (-8 IN. Hg)</p> <p>WITH PRECOLLECTOR:          INITIAL <b>7.8</b> (IN. Hg)          FINAL <b>6.0</b> (IN. Hg)       </p> <p>WITHOUT PRECOLLECTOR (ONLY IF LEAKS FOUND ABOVE):          INITIAL <b>7.8</b> (IN. Hg)          FINAL <b>7.8</b> (IN. Hg)       </p>	<p>STAGE TWO (SECOND PLATE, NO <b>3</b>) <b>23 GOOD PEAKS</b></p>
<p>NOTES AND OBSERVATIONS</p>	<p>STAGE THREE (THIRD PLATE, NO <b>4</b>) <b>23 GP</b></p>
<p><b><math>\bar{V} = 50</math> FPS</b></p> <p><b>PRE</b></p> <p><b>LEAK AT PRECOLLECTOR NOZZLE, SMALL</b></p> <p><b>POST</b></p> <p><b>BF STICKING TO F. COMBINE THESE WEIGHTS FOR DATA ENTRY.</b></p> <p><b>NOZZLE GOOD, NO NICKS.</b></p>	<p>STAGE FOUR (FOURTH PLATE, NO <b>5</b>) <b>23 GP</b></p>
	<p>STAGE FIVE (FIFTH PLATE, NO <b>6</b>) <b>23 GP</b></p>
	<p>STAGE SIX (SIXTH PLATE, NO <b>7</b>) <b>23 GP</b></p>
	<p>BLANK OR BEHIND DISK (CIRCLE ONE) <b>23</b></p>
	<p>BACK UP FILTER <b>23 AND I 23 BF BLANK FILTER IS STICKING TO THE DIRTY FILTER. MUST COMBINE AND WEIGH AS ONE PACKAGE</b></p>

Figure 9

Example of a completed Run Sheet - Run Side.

RUN CODE		DATE		DIFFERENTIAL STACK PRESSURE						
SAMPLE CALC		4-20-84		-0.3 (IN H <sub>2</sub> O)						
CONTROL BOX ID		START TIME		AMBIENT PRESSURE						
RAC # 1		0900		(AS BAROMETER) 29.60 (IN H <sub>2</sub> )						
GAS METER ID		END TIME		AMBIENT TEMPERATURE						
RAC # 1		1110		74 (F)						
THE CALCULATED TARGET JM VALUES REQUIRES THE OPERATOR TO USE		SAMPLING DURATION		-60 SEC LEAK TEST-						
ORIPICE ID		120 (MIN)		PRE HOT						
1205		GAS METER-START		A. 15 IN. Hg W/SAMPLER .016 FT <sup>3</sup>						
SAMPLING ASSIGNMENT		321.450 (FT <sup>3</sup> )		B. 5 IN. Hg W/SAMPLER .007 FT <sup>3</sup>						
INLET (OUTLET) OTHER:		GAS METER-FINISH		C. 15 IN. Hg W/C SAMPLER _____ FT <sup>3</sup> POST HOT						
		361.640 (FT <sup>3</sup> )		0.017						
TARGET JM		TOTAL VOLUME BY GAS METER		NOTE: RELEASE VACUUM AT NOZZLE TO AVOID RUPTURING FILTER. PASS 50.02 FT <sup>3</sup> FOR A OR B OR C VISUAL CHECK OF NOZZLE						
0.44		40.190 (ACF)		OK						
RUN TIME (MIN)	PORT NO. TRAVERSE POINT	GAS METER READING	GAS METER TEMP (F)	FLUE GAS TEMP (F)	ORIPICE JM (IN. H <sub>2</sub> O)	PUMP VACUUM (IN. Hg)	PROBE TEMP (F)	CONDENSER ID NO. RAC # 1		
								CONDENSER H <sub>2</sub> O CATCH 39 (MM)		
1	5 A1	321.450	72	300	.44	2	310	DRYING COLUMN WEIGHT CHANGE		
2	10 A2	24.00	74	301	.44			ID NO. E INITIAL WT. 1+478.0 (GM)		
3	15 A3	26.47	74	300	.44			W/10 HOSE FINAL WT. 1+482.0 (GM)		
4	20 A4	28.15	74	301	.44			(1 gm = 1 mm) H <sub>2</sub> O GAIN 4.0 (MM)		
5	25 A5	29.82	74	301	.44			TOTAL VOLUME H <sub>2</sub> O 43.0 (MM)		
6	30 A6	31.50	74	301	.44	3.3	300	NOTES AND OBSERVATIONS		
7		MOVE						CO <sub>2</sub> = 0.22% dry		
8	5 B1	33.17	74	298	.44			O <sub>2</sub> = 19.75% dry		
9	10 B2	34.85	74	300	.44			NO PLANT UPSETS DURING RUN.		
10	15 B3	36.52	74	300	.44					
11	20 B4	28.20	74	298	.44					
12	25 B5	39.87	74	302	.44					
13	30 B6	41.54	74	300	.44	4.5	305			
14		MOVE						SAMPLING LOCATION		
15	5 C1	43.22	74	300	.44			INLET (OUTLET)		
16	10 C2	44.89	74	300	.44			IN THE SPACE BELOW GIVE THE UNIT, CHAMBER, DUCT PANTLEG, ETC WHERE THE SAMPLER WAS RUN		
17	15 C3	46.57	74	298	.44			UNIT 3 ESP OUTLET		
18	20 C4	48.24	74	299	.44			PORT NUMBER(S)		
19	25 C5	49.92	74	300	.44			ALL		
20	30 C6	51.59	74	301	.44	6.0	300	A, B, C, D		
21		MOVE						SAMPLER ORIENTATION (CIRCLE ONE):		
22	5 D1	53.27	74	299	.44			HORIZONTAL		
23	10 D2	54.94	74	302	.44			TOP ENTRY VERTICAL		
24	15 D3	56.62	74	300	.44			W/ TURN AROUND		
25	20 D4	58.29	74	298	.44			W/O TURN AROUND		
26	25 D5	59.97	74	301	.44			BOTTOM ENTRY VERTICAL		
27	30 D6	61.64	74	300	.44	7.2	305	OTHER		
28	END RUN				361.640	1110	hrs.			
29					120 MIN. TOTAL SAMPLING TIME					
30	POST TEST CALCULATIONS:									
120	TOTAL	40.190								
	AVG.		74	300	.44					
								OPERATORS		
								(1) JWR	(2) SJG	

<u>DESCRIPTION</u>	<u>NUMBER ON PETRI DISH</u>
Precollector	
Precollector Substrate Foil	I23P
Zero Stage (Impactor Inlet Throat)	
Collection Disk and Substrate (Solid Disk)	I23D
First Jet Plate (No. 2)	
Collection Disk and Substrate (Donut)	I23-1
Second Jet Plate (No. 3)	
Collection Disk and Substrate	I23-2
Third Jet Plate (No. 4)	
Collection Disk and Substrate	I23-3
Fourth Jet Plate (No. 5)	
Collection Disk and Substrate	I23-4
Fifth Jet Plate (No. 6)	
Collection Disk and Substrate	I23-5
Sixth Jet Plate (No. 7)	
Collection Disk and Substrate	I23-6
Blank Collection Disk (Inverted)* and Substrate	I23-BX
Teflon Insert Ring**	
Filter	I23F***
Teflon Insert Ring**	
Teflon Insert Ring (BF)**	
Blank Filter	I23BF***
Teflon Insert Ring (BF)**	
Support Screen	

Notes:

\*The Extra Collection Stage can be used in either of two different locations. If this is an outlet run the extra collection stage is used as a blank. The blank is a collection stage (loaded with a number substrate) that has been inserted upside down (out of the flow) directly behind the collection plate of the last jet. It is referred to as a blank because it is not preceded by a jet stage and is oriented out of flow. It is intended to act as a check in weighing and for any flue gas-substrate interactions. It is treated the same as all the other substrates for conditioning and handling. Because of high loadings at an inlet sampling location, it may be placed directly beneath the solid disk which precedes the first multijet stage to catch any overload or blow-by from the zero stage (impactor inlet and solid disk). Usually at inlets the run time is so short and the flow rate so low that no problems are encountered from the gas-substrate interactions. Outlet loadings are typically low enough that zero stage overloading is not normally a problem, thus this collection substrate is used as a blank rather than a safety.

\*\*Thin light weight Teflon may be cut in a donut shape and placed in front of and behind a filter to prevent the filter from sticking to the metal. The Teflon rings should be



weighed with their respective filters. Kapton plastic film can be used if the flue temperatures are too high for Teflon.

\*\*\*The petri dish with the filter also contains the filter's pouch (aluminum foil envelope) and the Teflon inserts. All of these pieces are weighed as a package rather than separately. The envelope remains in the petri dish while the inserts and filter are loaded into the impactor. The purpose of the envelope is to prevent particles falling off the filter prior to and during the post-test weighing. Note: The pouch must be open during desiccation in order to permit moisture to escape from the filter.

The filter package (I23F) consists of one filter, one pouch, and two Teflon inserts. The total weight of these four pieces is assigned to I23F in the weight records. The blank filter package (I23BF) consists of one filter and two Teflon inserts. The pouch is not necessary but may be desirable. The total weight of these three or four pieces is assigned to I23BF in the weight records. The third and fourth Teflon inserts are marked BF to avoid confusion between them and the other two during unloading.

#### 4.2.4.3 SAMPLING TRAIN PREPARATION

Preparation of the sampling train is basically the same as that for a Method 17 run. The one major difference is that the equipment is modified to permit the use of smaller orifices when lower flow rates are required. The other difference is that a metal condenser and preweighed drying column (Figure 1) are commonly used in lieu of the glass impingers. All manometers should be leveled, leak checked, and zeroed. Then the backhalf of the sampling train should be leak checked as described below.

#### 4.2.4.4 LEAK CHECKS

In general the backhalf of the sampling train must be tested at the beginning and the end of each field test (and again if components are changed or the equipment is moved). Each impactor will be checked at least twice, and possibly four times. The last two tests are acceptance tests and the first two may be thought of as screening tests aimed at finding and correcting leaks in an advantageous manner. The first test (optional) is performed in the lab before the impactor is carried to the stack. The second (optional) is made before the impactor is warmed up. If leaks are found during the prerun hot leak checks they must be corrected before the run may proceed. As the impactor may cool down during this time, one may be forced to repeat the 45 min. to 1 hr. warmup time.

The significance of a leak and the acceptance limits assigned to a leak depend on where it occurs. For example, a leak around a nozzle attachment means that all the gas does pass through the precollector and impactor thus impactor performance is not affected. Likewise, a leak between the precollector and impactor inlet flange means the gas passed through the impactor but bypassed the precollector. A leak downstream of the impactor would not be acceptable because the dry gas meter reading is greater than the actual amount of gas sampled by the impactor. Once the impactor run has been

completed it could compromise the data to disassemble the unit and try to isolate the location of a leak. Leaks affect not only the indicated amount of gas sampled but also the calculated  $D_{50}$ 's, thus data cannot be salvaged by making leak rate corrections.

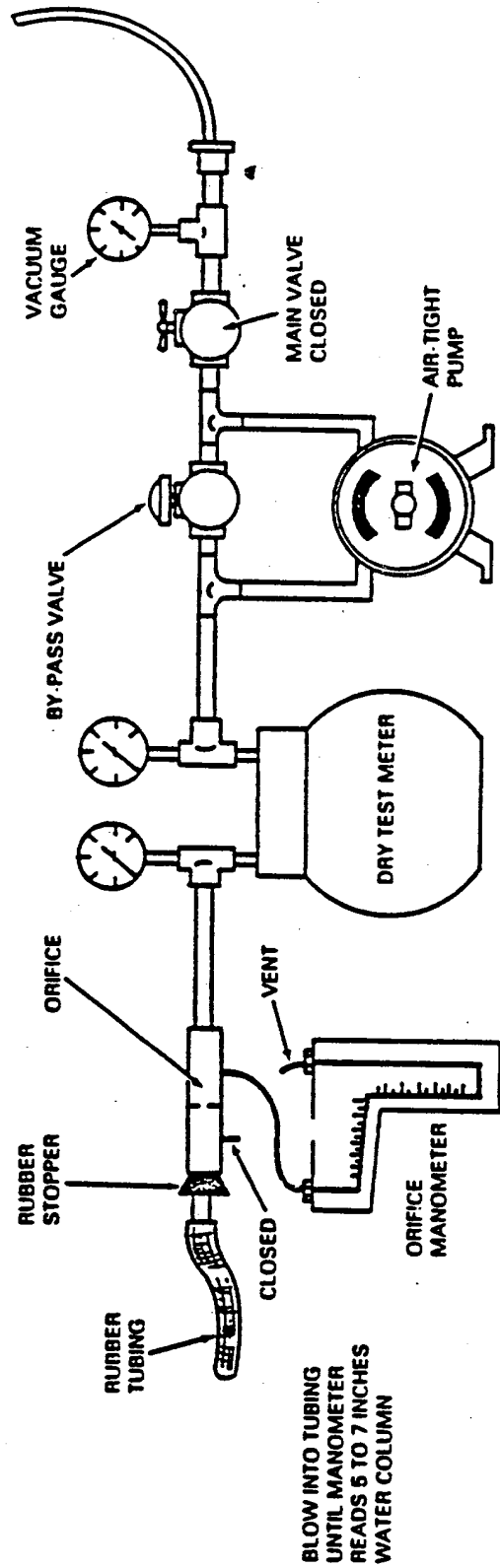
Many different techniques are available for leak checking a sampler. The particular techniques used to perform any pre-test cold checks are optional as these are all aimed at finding leaks before the run is performed. Although the pre-test cold leak checks are optional, it is highly recommended that some form of check be made prior to warmup. Such checks can locate leaks early and prevent unnecessary delays. The pre-test hot leak test and the post-test hot leak check are mandatory. It is these tests which accept or reject a run with respect to leaks. The techniques used for these tests are spelled out in detail in the following paragraphs.

**Initial Set-Up Check of Meter Box Backhalf:** Each time the sampling train is set up (desired orifice installed on the dry gas meter) the meter box should be checked as described below. The normal leak check procedure will not detect leaks on the positive pressure side of the pump as such leaks are discharged to ambient, never reach the dry gas meter, and thus less volume is recorded than sampled. Once this check has been performed it need not be repeated until the meter box is moved or the orifice is changed. If this initial check (and any equipment change checks) is not made, all subsequent leak checks are subject to question. The results of this check should be recorded in a field test log book (a chronological record of what took place during the field test). The procedure (see Figure 10) follows (the same as used with a Method 5 train): Close the main valve on the meter box. Insert a one-hole rubber stopper with rubber tubing attached to the orifice exhaust pipe. Disconnect and vent the low side of the orifice manometer. Close off the low side orifice tap. Pressurize the system to 5 to 7 in. water column by blowing into the rubber tubing. Pinch off the tubing and observe the manometer for one minute. A loss of pressure on the manometer indicates a leak in the meter box. Leaks, if present, must be corrected (A soap solution is helpful for locating the source of leaks in a pressurized system.)

#### 4.2.4.4.1 LAB LEAK CHECKS

A simple vacuum check is sufficient. Assemble the impactor and precollector. Connect a vacuum source to the impactor outlet (pump off). Plug the nozzle and turn the pump on, adjusting the pump valves to about 8 inches Hg negative differential to ambient. Then close off the line between the impactor exit and pump and see if the system holds this vacuum. If it falls a leak is present. The rate at which it falls indicates the size of the leak. If leaks are present, one may switch to a slightly positive pressure (6 in. of water) and use a soap solution to locate the source(s) of the leak(s). Usually these will be due to missing o-rings, loose fittings, etc. these should be corrected before the sample is sent to the sampling platform. Note: Release the vacuum at the nozzle to avoid damage to the filter.

FIGURE 10



*Leak check of meter box.*

#### 4.2.4.4.2 COLD LEAK CHECKS

At the sampling platform the sampler is connected to the probe and a cold leak check is performed (optional). As shown on the run sheet, the criterion is a leakage rate  $\leq 0.02$  ACFM. The test is first done at  $-15$  in. Hg with the precollector and sampler attached. If the system fails this test, the operator should attempt to fix the leak by checking the most common problem areas such as loose connections, etc. The test may then be repeated at the  $-5$  in. Hg level (line B on the run sheet). If it still fails to meet specifications, one needs to isolate the source (sampler or the train). Line C may be used for this purpose. Any leaks should be located and corrected before warming the impactor, otherwise the pre-test hot leak test may prohibit the run from being started. Wrapping the entire impactor assembly with aluminum foil at this time is advantageous. This prevents the outer surfaces and joints from accumulating particulate matter during warmup and sampling. Such an accumulation can make disassembly difficult or even result in the loss of a run if any of the material is dislodged onto a substrate when one impactor is unloaded.

#### 4.2.4.4.3 HOT PRE-RUN AND POST-RUN LEAK CHECKS

After the warmup is completed, the hot sampler is removed from the port, the cover is removed from the nozzle, and the hot pre-run leak check is performed. Plug the nozzle with a material that will be able to withstand the nozzle's high temperature than turn on the pump and draw a vacuum in the system equal to or greater than the maximum value reached during the previous sampling run. Record this rate as  $L_N$ . Table 1 (Leak Test Criteria) gives instructions and criteria in a flow chart form. Note that unlike Method 5, flow rate corrections are not permitted because such corrections affect the  $D_{50}$  as well as the total volume sampled.

After the run is completed and the hot sampler is removed from the last port, the hot post-run leak check is performed to verify that no leaks developed during the run. The criteria of Table 1 are used for this purpose. One must not attempt to remove the nozzle or disassemble that sampler at this time in order to isolate a leak. The only permissible leak is at the nozzle and a comparison is made between pre-run and post-run leak rates. The sampler is removed and the train is checked to verify that all measured gas went through the sampler.

The following leak-check instructions for the sampling train described in APTD-0576 and APTD-0581 may be helpful. Start the pump with the by-pass valve fully open and coarse adjust valve completely closed. Partially open the coarse adjust valve and slowly close the by-pass valve until the desired vacuum is reached. Do not reverse direction of the by-pass valve. If the desired vacuum is exceeded, either leak-check at this higher vacuum or end the leak-check as shown below and start over. When the leak-check is completed, first slowly remove the plug from the inlet to the sample nozzle and immediately turn off the vacuum pump. This prevents water from being forced backward and keeps silica gel from being entrained backward.

#### 4.2.4.5 RUN SHEET INSTRUCTIONS

The run sheet accompanies the impactor at all times. All information and comments relating to the run are recorded on this document. Figure 6 shows the side of the run sheet used by lab personnel to record identifying equipment numbers and to record observations made while unloading the impactor. This data form is specific to the University of Washington impactor configured with the precollector, six jet plates, control blank, and filter, as this is the recommended ARB preferred instrumentation and configuration. Use of other impactor or configurations will require minor alterations to this form. Figure 7 shows the other side of the run sheet. This side is used by the testing personnel during the run, example data is shown in Figures 8 and 9. Appendix A shows an alternative version of the run sheet prepared by the Computer Programs. Entries to the alternative form are smaller to those described herein for the "manual" version shown in Figure 7. The circled numbers relate to additional information given below. The prefixes L and U are used to identify information recorded by laboratory personnel during loading (L) and unloading (U). Unprefixed members identify information recorded by testing personnel at the sampling location before, during, and after the run. The number sequence represents the normal sequence one would use in recording the information. One major difference between impactors and a Method 5 train is the use of a constant flow rate. On a Method 5 run the operator monitors point velocities and adjusts the sampler flow rate to maintain isokinetic sampling at each traverse point but impactors require a constant flow rate. With impactors a Method 2 velocity traverse is performed before the run and the techniques described in Section 4.2 are used to select the traversing procedures for one or more runs, each of which is made at constant but possibly differing flow rates. The desired flow rate for a run will be obtained for stack conditions when the train is operated at the Target H (pressure drop across for the orifice) listed on the run sheet.

## Table 1 Leak Test Criteria

### Definitions:

- $L_N$  = leak rate with Nozzle, Precollector, Impactor and Trains
- $L_T$  = leak rate, assembly removed from probe (Train only)
- $L_a$  = 0.02 cfm or 4%  $Q_i$  whichever is smaller (acceptable leak rate)
- $L_M$  = 10%  $Q_i$  (maximum acceptable leak rate), 10% Trash Point

All pre-run testing is performed at the highest pressure drop obtained in most previous runs. The Post-run testing is performed at the highest pressure drop obtained in the actual run.

For Hot Pre-run Test, the term "Reject Run" means that the leaks must be corrected before the run may proceed. This will usually mean the unit must be returned to the lab and reassembled.

### Pre-test, Hot

#### Plug Nozzle, Test (Record $L_N$ )

- |               |   |
|---------------|---|
| $L_n < L_a?$  | Yes: Acceptable<br>No: Attempt to correct leaks, retest                 |
| $L'_N < L_a?$ | Yes: Acceptable<br>No: Continue   |
| $L'_N > L_M$  | Yes: Reject Run<br>No: Remove Impactor Assembly, Retest (Record $L_T$ ) |
| $L_T < L_a?$  | Yes: Acceptable<br>No: Reject Run                                       |

### Post-Test Hot

#### Plug Nozzle, Test (Record $L_{Npost}$ )

- |                                 |  |
|---------------------------------|--|
| $ L_{Npost} - L_{Npre}  > L_M?$ | Yes: Reject Run or tighten Nozzle and retest<br>No: Continue, do not attempt to correct leaks.<br>Do Not remove nozzle<br>Remove Assembly (Precollector/Impactor)<br>from Probe, Plug Probe, Test<br>(Record $L_{Tpost}$ ) |
| $L_{Tpost} < L_a?$              | Yes: Acceptable<br>No: Reject Run  |

#### 4.2.4.5.1 LAB PRE-RUN ENTRIES (15 ITEMS)

(L1) Run Code: This key number is usually assigned in the written test plan and will generally include abbreviations for the plant name, sampling location (inlet, outlet) and sequence number at this location (see Manual Appendix A). This same code is also listed at (L8) on the Run Side.

(L2) Substrate Set Identification No.: This is the number assigned in the Weight Book to the substrate set. This set includes one or two filters and substrates for the precollector, zero jet (solid disk), six jet plates (donuts), and one blank collection plate (donut) as listed on the right side of the form. This set number together with the sequence information (P, D, 1-6, BX, F and BF) is marked on the petri dish for each member of the set (Example: 126F, Impactor substrate set No. 26, filter).

(L3) Person loading impactor and data loaded: With a small test crew many of these items are not important but on a larger test where eight to ten runs are made per day this can avoid a lot of confusion in answering questions related to the run.

(L4) Hardware Identification: When a substrate set is loaded in an impactor, this information must be completed and the run number marked on the impactor shell. This information identifies which jet plates were loaded in the impactor during the run. The Nozzle Diameter is the calibration value for the nozzle and is used in the calculation of the target  $\Delta H$  value. Nominal Diameters are also shown in fractions.

(L5) First Jet Plate No.: This information has already been recorded on the stage configuration line in the Hardware Identification section. As such these blanks are optional and are simply added for clarity. These numbers are read from the back side of the plates. (The plates should have been permanently marked when the hole verifications were made.) At (L5B) one of the two choices "Blank" or "Behind Disk" should be circled to indicate where the extra collection plate was loaded, upside down and directly behind the collection plate of the last jet stage or right side up and directly behind the zero stage (entrance jet) solid disk collection plate to catch any overloading from the disk.

(L6) Lab Leak Check: The first check is performed with the precollector mounted on the impactor. If a leak is present which cannot be corrected by inspecting and tightening fittings, then the impactor should be checked without the precollector in order to determine if the leak is in the precollector or the impactor. Small leaks in the precollector are acceptable. Leaks in the impactor should be located and corrected before sending the assembly to the sampling site. Use of a slightly positive pressure (less than 8" H<sub>2</sub>O) and a foaming leak detector liquid can be helpful in locating the leaks. Be careful not to reapture the filter by causing air to rush through it in the wrong direction. Always release the vacuum slowly at the precollector inlet, not by turning the pump off.

(L7) Real or Blank: The lab personnel should circle the appropriate description. Although the presence of a filter (in place of the precollector) at the inlet of the impactor obviously identifies the run as a blank rather than a real, the circles are used to facilitate identification during data processing. Frequently this will be redundant since the Run code would normally identify the run as being a blank.

(L8) Run Code: Same as (L1), listed on both sides of the form.

(L9) Control Box ID: This is the assignment of the impactor to a specific sampling train. This is necessary because the orifices in the different sampling trains generally have different calibration constants. Consequently, an assignment must be made before the Target  $\Delta H$  value can be calculated.

(L10) Gas Meter ID: When the Control box ID is specified, this selects the gas meter since it is an integral part of the Control Box. The gas meter must be identified so that the appropriate dry gas meter calibration factor (Y) can be used for data reduction.

(L11) Orifice ID: As impactors may require the use of orifices of different diameters to cover the broad range of flow rates which may be needed, it is necessary to identify which specific orifice is to be installed by the testing personnel. The orifice calibration factor ( $\Delta H@$ ) of the specified orifice is used in the calculation of the Target  $\Delta H$  value.

(L12) Sampling assignment: The test plan will frequently identify the areas where sampling is to be performed and distinguish between these different areas by the abbreviations used in the Run Code. In that respect, this line is redundant. It has been included for the purpose of clarity. Frequently different stage configuration and flow rates will be used in the different sampling areas (inlet, outlet zone to be traversed, etc.) and the loaded impactor (stage configuration used) and calculated Target  $\Delta H$  will only be appropriate for one of these areas. Thus, the need to clearly identify the sampling assignment is established.

(L13) Target H: This is calculated using the computer program in Appendix A and the equations given in Section 6 for the equipment arrangement shown in Figure 1. This pressure drop across the orifice (as specified in (L11)) should be maintained throughout the run.

(L14) Drying Column ID No.: Both an ice bath condenser and silica gel drying column are used. The triple beam balance (1/10 g) is usually maintained in the lab and to avoid confusion, the drying columns are numbered. This number shows which drying column was used with which impactor.

(L15) Drying Column Initial weight: The weight of the drying column specified above is recorded on the Run Sheet. The weight gain of the drying column is used in the determination of the stack moisture value ( $B_{ws}$ ). Note: 1gm = 1mL, 1 mL liquid = 0.04707 ft<sup>3</sup> vapor at standard conditions (68° F, 29.92 in. Hg).



#### 4.2.4.5.2 STACK ENTRIES (32 ITEMS)

At this point the Run Sheet, Drying Colmn, and Impactor are ready to be given to the testing personnel and carried to the appropriate sampling site. The following entries are made by the testing personnel.

- 1) Date: This is the date the run is performed. It may be different from the date it was loaded.
- 2) Differential Stack Pressure: This reading was made during the Method 2 pitot traverse performed prior to the impact run.
- 3) Ambient pressure: This may be directly if a barometer is at the sampling site (mark through LAB) or, if the barometer is in the lab (and the lab is at ambient pressure), altitude corrections can be made, 0.1 in. Hg/100 ft. If a reading is taken from the plant control room, be sure the reading is measuring ambient pressure and not absolute pressure at some point in the plant process.
- 4) Ambient Temperature: Temperature at the start of the test.
- 5) Prerun Leak Test: This is described in Section 4.2.4.4.3. The COLD TEST is optional but recommended. The HOT Pre-run and Post-run test are required. To end a leak test and avoid rupturing the filter, the vacuum should always be released at the nozzle with the pump running. This sets the direction of the flow through the filter so that the filter will be supported. Look at L6 to see if the precollector leaks. Even if the lab test indicates a leak, the stack test is a different kind of test (a quantitative measure) and may prove to be acceptable. If the system fails Test A (15 in. Hg) then Test B should be performed. If B fails and the lab test showed a leaking precollector, the precollector should be removed and Test B repeated. If it still fails then Test C should be performed to see if the leak is in the impactor or the train.
- 6) Condenser ID No: List the ID No. Some condenser designs do not permit all the water to be removed. Residual amounts are trapped. Before using such a condenser add some water to the condenser then pour it out using the same technique that will be used after the run is completed. This preloads the entrapment areas to permit an accurate reading the the subsequent catch.
- 7) Sampling location: This describes where the sample is run. To avoid replicate detailed drawings reference is often made to figures and to descriptions in the test plan. This should agree with the Sampling Assignment. Space is provided to permit a detailed description.

- 8) Sampler Orientation: This is an extension of (7). It is important to know if the sampler was operated horizontal, right side up, or upside down. If a sampler is operated upside down, flow must be maintained while the sampler is removed from port to port while traversing. The sampler must be right side up or horizontal before flow is stopped. Any gas sampled while moving from port to port should be discounted in data analysis. A written record of orientation may be useful later if problems are encountered in interpreting the data.
- 9) Operator: The test personnel must identify themselves so that they can be called upon at a future time to answer questions.
- 10) Blank Space: This may be used as desired. Frequently the time at which the impactor was inserted for warm-up will be listed (Example: start warm-up at 1322).
- 11) Start Time: This is the time the run actually starts. As a stop watch is normally used for the traversing dwell times, this and item #28 will generally be the only recorded clock times (unless item #10 is used as above). Sufficient warm-up must have been completed by this time. Usually this entry is made shortly after insertion for in-situ warm-up and indicates the scheduled start time. If something prevents the run from being started at this time, simply mark through the entry and write the correct actual start time. Note: During the end of the warm-up time the pump should be running with the shut-off valve closed.
- 12) Sampling Duration: This is the actual run time, theta. Usually this entry is made before the run is started and indicates the scheduled run time. If something happens to change it during the run, it should be properly noted on the bottom portion of the run sheet. The operator should then mark through this entry and write in the corrected actual run time. Lab personnel will certify this after the run and make the same entry in U7.
- 13) Gas Meter-Start: This is recorded here and in (16) after the probe has been leak checked and inserted for warm-up. This is recorded to the nearest 1/1000 ft (see example). Pump is running with shut off closed. This is one of the most important entries on the page.
- 14) Run Time Column: As shown in the example, this column and column 15 are usually completed before the run is started and show the scheduled dwell time at each traverse point. If the schedule is altered one can mark through the entry and either write the corrected entry to the left or use the blank column (19). Note: The implied meaning is that the listed time marks the end of the dwell (not the beginning) and the gas meter reading was recorded on the fly at the indicated time. Immediately after this indicated time, the probe is positioned to the

next traverse point. In the example on line 3 the implied meaning is that from stop watch time 10 to time 15 the probe was at position A3 and the DGM reading at time 15 was 795.64 (approximately, since the needle was moving). If desired, clock times may be used for very long runs. For a run of about two hours or less, use of stop watch time as shown in the example is recommended. Clock times may be entered to the left of the appropriate line number (or in the blank column) if so desired.

- 15) Port No./Traverse Point Column: See explanation in (14) above. The entry on the "Pre" line and on line "1" are the same. "Pre" implies at or near start.
- 16) Gas Meter Reading Column: "Pre" is same as (13). During the run (22) this is the approximate reading (moving) at the indicated stop watch time. See also (14).
- 17) Gas Meter Temp, Pre: The pump is not sampling stack gas at this time so this temperature will be lower than the run temperature. During the run (23) the operator should record the temperature at some point during the dwell at this traverse point.
- 18) Flue Gas Temp, Pre: The purpose of this entry and (20) is to remind the operator that the probe heater should be working. Probe heat prevents the accumulation of water (in the probe) which could back wash the filter and substrates.
- 19) Blank Column: May be used as desired (see (14)).
- 20) Probe Temp, Pre: Entry is to remind the operator to turn on the probe heater (see 18).
- 21) See (14) and (15).
- 22) See (14) and (16).
- 23) Gas Meter Temperature Column: This is the temperature of the dry gas meter, read shortly before the dry gas meter reading is taken.
- 24) Flue Gas Temperature Column: This is a reading of the temperature of the flue gas at this traverse point, read sometime during the dwell at this point.
- 25) Orifice  $\Delta H$  Column: The Target  $\Delta H$  value (L13) is the desired value. This column is intended to be a record of the actual  $\Delta H$  as well as a

reminder to adjust the valves as necessary to maintain the flow at the Target  $\Delta H$  value (compensate for filter loading).

- 26) Pump Vacuum Column: This is a pump inlet vacuum read toward the end of the dwell at this traverse point.
- 27) Probe Temperature Column: This is a probe temperature read sometime during the dwell at this traverse point. This is a reminder to verify that the probe heaters are working to prevent condensate from draining back to the filter. This information is not used during data reduction.
- 28) End Time: This is the 24 hr. clock time when the run was actually ended. The interval between start and stop will generally be longer than the sampling duration because the flow is normally cut off and the timer stopped when the probe is moved from one port to the next.
- 29) Gas Meter-Finish: This is the reading of the gas meter when the run is stopped by closing the shut-off valve with the pump still running.
- 30) Post-run Leak Test and Visual Check of Nozzle: After the run has been stopped (with pump running) and the final gas meter reading recorded, the probe is removed from the stack and the Post-run Leak Test described in Section 4.2.4.4.3. is performed. This is similar to the test described in (5) except that it is performed post-test. This test is mandatory and is used to accept or reject the run with respect to the leaks. At this time the operator should also visually check the nozzle to verify it was not damaged (banged, scraped, etc.) during the course of the run. If the nozzle appears undamaged place a check mark in the box. If the nozzle is damaged write in the word "Damaged" and make appropriate entries in the Notes and Observations section.
- 31) Condenser H<sub>2</sub>O Catch: After the hot leak test has been completed, the sampler is removed from the probe. The operator will then shake the umbilical to drain water in the line into the condenser. The line to the drying column may also contain some water droplets and should be drained into the condenser. At this time the condenser is removed and a graduated cylinder is used to measure the amount of water that was captured by the condenser. This value is recorded here. The length of tubing connecting the drying column to the control box inlet should be disconnected at the drying column and the short length of tubing connecting the drying column to the condenser should be re-connected where the other tube was removed. This loop will close off the drying column to prevent any loss or gain of water. The drying column, with tubing, is ready to be returned to the lab for weighing.

- 32) Notes and Observations: Any notes or observations not yet recorded should be entered at this time.

#### 4.2.4.5.4 LAB POST RUN ENTRIES (12) ITEMS

At this point the SAMPLER, RUN SHEET, and DRYING COLUMN are ready to be returned to the lab for analysis and turn around. The following entries are made by the lab personnel.

- (U1) Drying Column Final Weight: The drying column is weighed and the value recorded here. Note: If the initial weight was done with a tube connected to the two ends, the final weight must be done with the same tube attached. The weight gain is calculated and recorded.
- (U2) Total volume H<sub>2</sub>O: This is the sum of the condenser catch and the drying column weight gain.
- (U3) Notes and Observations: This space may be used as desired.
- (U4) Person Unloading Impactor and Date Unloaded: Used to identify the person unloading the impactor and when it was unloaded (see also L3).
- (U5) Observations: If you wish to record any observations made while unloading the precollector and impactor, this is the place to make the notes. Such observations as obvious indications of bounce or overloading, hunks of rust (from nozzle scrapings) in the precollector, ruptured or wet filter, damaged o-ring, dramatic color changes from stages to stage, etc. are listed on the appropriate line.
- (U6) Total Gas Meter Volume: This is the value obtained by subtracting the START reading from the FINISH reading. The readings in the gas meter column (22) should be examined to verify that this is the actual start and finish values. This is the most important number on the Run Sheet.
- (U7) Post-Test Calculations-Run Time: This is the same as (12) and is optional. The common usage is to examine the column to determine the total run time and be sure that the "planned" duration and the "actual" duration are the same.
- (U8) Post-Test Calculations-Gas Meter Reading: This is the same as (U6), total volume sampled, and is operational.
- (U9) Post-Test Calculations-Gas Meter Temperature: This is the simple average of the values listed in the column. Data reduction equations assume the gas meter was operated at a constant temperature. The average value is used as that value.

- (U10) Post-Test Calculations-Flue Gas Temperature: This is the simple average of the values listed in the column. The data reduction procedures assume that the flue gas temperature was constant. The average value is used as that value.
- (U11) Post-Test Calculations-Blank Column: If the blank column is used and if an average value is desired it is recorded here.
- (U12) Post-Test Calculations-Orifice  $\Delta H$ : This is the simple average of the values listed in the column. This value is not used in the data reduction but if it differs from the Target  $\Delta H$  value the calculations of % isokinetic value (%I) will probably be different than 100%.

Summary: All written comments and data related to a given impactor run should be recorded on the run sheet. Only the substrate weight records and velocity traverse information are recorded on other forms. The three most important data elements recorded are the Sample Duration (0), Total Volume Measured by Gas Meter ( $V_m$ ), and Total Volume H<sub>2</sub>O collected ( $V_{1c}$ ). All entries are important but these are essential.

#### 4.2.4.6 PARTICULATE TRAIN OPERATION AND DATA RECORDING

Once preliminary velocity traverses, selection of stage configurations and nozzle diameters, and pre-test cold leak checks are completed, the nozzle is covered securely and the sampler is inserted into the flue gas and rotated out of flow for warm up. Aluminum foil and high temperature fiberglass tape serve well for covering the nozzle. Once the impactor is at the desired operating temperature the probe may be withdrawn from the stack, the cover removed and the pretest hot leak check performed. Once the leak test is completed the assembly is reinserted in the stack. The sampler must be at stack temperature when sampling begins. Depending on how long the leak check takes the second warmup may be as short as 5-10 minutes. The first warmup time will generally be about 45 minutes to one hour. Probe heaters are turned on at the start of the warmup time. This will insure that vapor does not condense in the portion of the probe outside the flue and drain back into the impactor backwashing the filter and lower collection plates during sampling.

Section 4.2.4.5 (Run Sheet Instructions) lists the various entries made to the run sheet before, during, and asfter the run. This run sheet serves as both a record and a guide. The most important data to be recorded before the run starts is the initial gas meter reading. The pump may be running during warmup with the cut off valve closed as the pump oil needs to be warm for the pump to be leak free. Using the Traversing Protocol described in Section 4.5.3.A.4, the impactor is positioned to the first sampling point and rotated into flow. The cut off valve is opened (with the pump running) and the flow adjusted to the Target  $\Delta H$  value. The impactor is then moved to the second traverse point at the appropriate time. Valves are adjusted as necessary throughout the run to maintain the Target  $\Delta H$  value and data is recorded on the run sheet. Flow is maintained

while the impactor is moved from one traverse point to another in the same port but the flow is stopped ( $\Delta H=0.00$ ) as the impactor is removed from one port and inserted into the new port. Flow is resumed at the first traverse point in the new port. [If, however, the impactor is operated in an upside down orientation (rather than a horizontal or upright orientation) the flow is maintained without interruption throughout the run until the impactor has been removed from the last port and oriented to a horizontal or upright position. Only then can the flow be stopped.] During traversing, move the impactor as smoothly and as quickly as possible without bumping or vibrating the sampler. When removing or inserting the sampler, take care not to scrape the nozzle on the port wall. Also, take care not to bump the sampler against the far inside wall of the flue.

When all the traverse points have been sampled for the desired dwell time the sample run is completed. Flow is then stopped and the sampler is removed from the stack. The post-test hot leak check is performed and the impactor/precollector assembly is then gently disconnected from the probe using as little motion as possible and allowed to cool before being transported to the lab. If the assembly was wrapped with foil, then foil should be removed at this time. The nozzle should be covered and the impactor oriented to an upright position. The condenser catch is measured and the drying column is removed for transport to the lab together with the sampler and run sheet. A wooden carrier is made especially for transporting hot impactors in an upright position is convenient for this purpose.

#### 4.2.4.7 ISOKINETIC CHECK

At this point the % Isokinetic should be calculated as described in Section 4.7.17 using the computer programs described in Manual Appendix A. Acceptable results are: 80% # 1 # 120 %. If "I" exceeds these limits, the run may be rejected.

It should be noted that only the large particles are affected by nonisokinetic sampling. Consequently, the information on the lower stages may be valid even if the isokinetic check is not met. Where multiple runs are made and only one has poor isokinetics, the outlier test used in the averaging of multiple runs (Section 4.2.7) will probably reject the bad data from the run and retain the data in the unaffected smaller sizes.

#### 4.2.5 SAMPLE RECOVERY

After the sampler has cooled down enough to be handled without gloves, it should be brought into the laboratory and carefully unloaded to remove the particulate matter caught. Great care is needed in this procedure to ensure that all the particulate matter is recovered and transferred to the appropriate containers.

If a cyclone precollector was used, remove the sample collected in the cyclone. With a small brush (a small nylon brush made for cleaning electric shavers is suggested), push the particles caught inside the nozzle down into the cyclone. Then, holding the cyclone upright on a table (or in a vise), carefully remove the cap and, holding the cap over the cyclone, brush the particles adhering to the bottom of the cap and to the outside of the

gas exit tube into the cyclone body. (A No. 7 camel's hair artist's brush is convenient here.) Then, lay the cap aside, being careful not to dislodge any of the particles inside the gas exit tube. Using a downward, pushing motion, brush the particles on the inside walls of the body of the cyclone down into the collection cup. Carefully detach the collection cup from the body and, holding the body over the cup, brush the particles adhering to the underside of the body into the cup. (At this point, all the particles caught by the cyclone should be in the cup.) If a cup insert was used, remove it with a pair of forceps for desiccation and weighing. If not, transfer the particles to a pre-weighed container. Wash the internal nozzle and cyclone surfaces with a solvent, such as acetone, into a preweighed bottle or aluminum cup. Cover the wash container loosely and allow the solvent to evaporate completely before desiccation and weighing.

If an impactor precollector was used, carefully remove the substrate with forceps as is done with impactor substrates. Brush the residue from the nozzle, body and outside of the gas exit tube onto the substrate or weighing container using the same techniques as for a cyclone precollector.

For either type of precollector, collect and weigh the particles adhering to the inside of the gas exit tube and to the connecting tubing from the precollector to the impactor as part of the catch for the first impactor stage. This may be done by washing and/or brushing this tube.

Carefully disassemble the impactor, and sequentially remove the substrates, inspecting each stage before it is placed on the weighing or storage container. Handle substrates sparingly with forceps, spatula, or clean dry fingers. Teflon o-rings are also used with the filter. Place the first filter on a thin aluminum foil envelope before and after the run to help prevent loss during handling. The envelope should be part of the initial and final weighings and should be labeled according to the filter it contains. The second filter is a control and is placed directly beneath the first filter, separated only by a set of Teflon o-rings. The second filter is clean and does not require an envelope.

Typically, some of the material that is deposited in an impactor is collected on surfaces other than the substrates, accumulating on interior surfaces such as gaskets or jet plates. Collecting this "misdirected" particulate matter is often troublesome. If the material is hard and dry, one may brush off the particles on to the appropriate substrate or into the weighing container. If the particles are sticky or wet, some type washdown procedure should be used. Use a solvent that is considerably more volatile than the particles. Also remove and weigh (with the sample) any pieces of substrate that stick to the stage. Generally, recovering material collected on the impactor wall is difficult, frustrating, and perhaps successful only on the inlet sections, where there may be a significant amount of material. By convention, all of the particulate matter collected between two consecutive primary collection surfaces is assigned to the second of the two stages. That is, all the material collected on surfaces between one substrate and another is considered to be part of the catch of the second, or lower, substrate. Material collected in the impactor inlet assembly is added to the first stage catch, (as is the nozzle catch if no precollector is used).



As the impactor is unloaded note the appearance of each stage, substrate, or cyclone in a notebook or run sheet such as was shown in Figure 9. Use a magnifying glass or low-power microscope to examine the deposits. The deposits below the impactor jets should appear as compact cones or spikes with little or no material appearing as streaks across the surfaces or “halos,” i.e., concentric rings around the main deposit.

#### 4.2.5.1 UNLOADING IMPACTOR

See Table 3.

#### 4.2.5.2 RELOADING IMPACTOR

See Table 2.

## Table 2

### Impactor Loading Procedure for the University of Washington Mark III/V Cascade Impactor

Note: All parts must be cleaned prior to assembly

#### A. Outlet Section

1. Secure outlet section of impactor in vise.
2. Place o-ring in groove at base of threads.
3. Teflon tape threads, approximately 1½ wraps.
4. Place filter support plate and fine screen in outlet section, support plate first, fine screen second.
5. When using a second (blank) filter for QA purposes one Teflon ring (marked BF) and blank filter are placed on top of the fine screen. The second Teflon ring marked BF is then placed over the filter. The filter assembly is then placed on top of the blank assembly as follows:  
Teflon ring, filter, Teflon ring. If stack temperatures exceed 425°F, Kapton may be substituted for the Teflon.
6. Check to ensure that the Teflon rings and filters are lying flat. Place the filter collar onto the outlet section and turn gently until the alignment pin on the top of the outlet section matches up with the hole in the filter collar. The filter collar should now be properly seated.
7. The inside edge of the top Teflon ring should be visible along the inside edge of the collar. If not, it should be replaced as the collar will cut the filter when the impactor is tightened.
8. Place an o-ring in the groove at the top edge of the filter collar.

#### B. Impactor Substrates

1. If a blank collection plate is to be included in the run, place the proper foil substrate in a collection plate. Place the collection plate on the filter collar with the substrate facing the impactor outlet (upside down).
2. Starting with the foil designated as the last collection substrate, place the foil in a collection plate and put it on top of the blank with the substrate surface facing up. If a blank is not used, this plate is placed directly on the filter collar with the substrate surface up.

3. The last jet plate (smallest flow area) is then placed on top of the collection plate. The jet plate should be oriented so that the jets are at the bottom, closest to the collection plate.
4. Place o-ring in groove at top of jet plate.
5. The remainder of the donut-shaped substrates should be loaded in the same way and added to the stack, alternating collection plates with jet plates.
6. When the last of the donut-shaped substrates and the corresponding jet stages have been placed in the stack, the zero stage collection plate should be loaded with the disk-shaped substrate and placed on top of the stack.
7. Align the stack, then slide the impactor cylinder (outer shell) over it. Tighten the cylinder onto the outlet section until it seals against the outlet section o-ring.

#### C. Inlet Section

1. Wrap Teflon tape approximately 1 ½ times around the threads of the inlet section.
2. Screw the inlet section (with connecting tube attached) into the impactor shell. Hand tighten only. Excessive tightening of the inlet section into the shell can cut the back up filter.

#### D. Precollector

1. Wrap threads of top and bottom sections and the nozzle 1 ½ times with Teflon tape.
2. Screw bottom section and nozzle into precollector body.
3. Remove foil from petri dish and curl slightly.
4. Insert foil into precollector body, greased side facing nozzle inlet.
5. Screw top onto precollector body.
6. Tighten precollector onto connecting tube (impactor body). Make sure the precollector is aligned such that the bend in the connector-tube offsets the nozzle.

#### E. Leak Check

1. Connect the inlet of the precollector/impactor assembly to the suction end of a pump by attaching a hose to the nozzle. Cap the outlet.
2. Pull a vacuum of approximately 10 inches of mercury on the assembly and observe the vacuum pressure for about a minute.
3. After this observation period is over, release the vacuum at the inlet, not at the outlet. Opening the outlet to ambient can rupture the filter.
4. Pressure losses of approximately four to five inches should be expected. Drastic leaks indicate loose fittings or missing o-rings. Attempt to correct any leaks. Use of a slightly positive pressure (6 inches of water) and a soap solution may help to locate the source(s) of the leak(s).
5. If small leaks are present which cannot be corrected, a leak check should be performed without the precollector.
6. Enter leak check data in appropriate space on impactor lab sheet.

#### F. Wrapping

1. On two small pieces of high temperature tape, write the impactor run code. Place one on the impactor and the other on the precollector.
2. Wrap impactor body and precollector with aluminum foil and secure with tape.
3. Rewrite impactor run code on the wrapped impactor body.

### Table 3

#### Impactor Unloading Procedure for University of Washington Mark III/IV

##### A. Preliminary

1. Hold impactor upright at all times.
2. Remove foil wrapping and blow off any loose dust from the impactor/precollector assembly with compressed air or gas. Cover nozzle with thumb to prevent blowing into precollector. Exterior surface should be clean to prevent contamination during unloading.
3. Secure outlet section in vise for disassembly.
4. Remove impactor lab sheet from run sheet notebook. As substrates are unloaded, observations such as broken peaks or loose particulate should be noted on the lab sheet.

##### B. Precollector and Impactor Inlet Section

1. Separate precollector from impactor where precollector attaches to the connector tube.
2. Unscrew top of precollector and remove foil from body, placing in petri dish.
3. Remove nozzle from precollector body and using clean dry brush, brush any loose particulate on the inside of the nozzle or the top section of the precollector onto the foil. Place nozzle to the side so that it can be washed in Step 7.
4. Separate body from bottom section and (using the same brush) brush any loose particulate in either section onto the foil. Place the brush to the side so that it can be washed in Step 7. Note: particulate on the inside of the exit tube (bottom section) should be transferred to the first substrate of the impactor.
5. Carefully fold foil in half twice and then loosely fold a small ridge on each side to prevent loss of particulate. The fold must be loose to permit drying during desiccation.
6. The tube connecting the precollector to the impactor should remain connected to the inlet section of the impactor. Any particulate in this tube should be brushed (using a second clean brush onto the first substrate in the impactor. This is best done by tapping the sides of the tube over the substrate, then brushing the interior of the tube with a small nylon bristle brush. The interior surface of the precollector exit tube (bottom section) should also be brushed onto the first

substrate in the impactor. Set tube/inlet assembly, precollector exit tube, and brush, to the side so that they can be washed in Step 8.

7. Washdown techniques as described in Section 4.2 of Method 17 may be used to rinse the nozzle and brush with acetone. The collected rinse must then be evaporated desiccated, and weighed on a precision balance. Note: It is important that the brushes used were previously cleaned by an acetone rinse and allowed to dry before being used to brush the particulate. As short straight nozzles are used, it may not be necessary to perform this nozzle washdown.
8. The precollector exit tube and the connecting tube between the precollector and impactor should also be washed into a second sample bottle. The evaporated dry weight gain from this washdown is assigned to the impactor's zero stage are shown in Figure 4-11 (Example Weight Sheet).

### C. Impactor Substrates

1. Loosen and remove the shell of the impactor. The impactor inlet section with attached connecting tube was removed in Step B8 above.
2. Inspect the interior of the shell for any evidence of internal leakage. If any such evidence is found, make a notation and try to identify the stage(s) with which it was associated.
3. Remove the zero stage collection plate from the stack. If the o-ring of the jet plate directly beneath the collection plate sticks, remove both plates from the stack.
4. Remove the disk-shaped substrate from the collection plate and place in its labeled petri dish. This is best accomplished by grasping the edge of the substrate with tweezers and rotating the disk gently.
5. If the jet and collection plates are stuck together, gently push the collection plate horizontally until the o-ring seal releases.
6. Each donut-shaped substrate should be removed in the same way and placed in its respective labeled petri dish.
7. Any particulate present on the surface of a jet plate should be brushed onto the substrate directly beneath it unless it is obvious that the material was removed or reentrained from the preceding substrate.

### D. Outlet Section

1. Gently lift the filter collar and brush any part of the filter adhering to it in the foil envelope.

2. Removing the outlet section from the vise, insert the handle of the brush into the outlet neck and gently lift the filter support plates.
3. Remove filters and Teflon rings from the plates and place respectively, dirty filter and two Teflon rings into the foil envelope and clean filter with two Teflon rings (labeled "BF") into its labeled petri dish.

#### E. Reloading Preparation

1. All parts of impactor and precollector should be blown off with compressed air or gas before being reloaded as described in Table 2.

#### 4.2.6 INSPECTION FOR PRACTICAL PROBLEMS

Manual Sections 3 and 4 discuss deviations from theory and practical problems. The purpose of this inspection is to verify that these problems have been successfully avoided or limited. This analysis consists of a visual examination of a completed impactor run and a study of the postrun dry weights. The analysis is summarized in the following paragraphs which give qualitative and quantitative guidelines. The problems discussed include cover nozzle scraping, bounce, overloading, underloading and negative weight changes. Additional inspection information is given in Section 6.2.

##### 4.2.1.6 NOZZLE SCRAPING

It is extremely easy to scrape a nozzle when inserting or removing the impactor from a port. If this happens, the results can be devastating. If the nozzle is significantly damaged as determined by the visual inspection made at the time of the postrun hot leak check it may be necessary to reject the run. Even if the nozzle is not damaged, scrapings from the port may invalidate the precollector catch. For this reason the precollector catch and zero stage collection plate (solid disk) should be inspected for particles that are obviously too large to have been suspended in the gas stream for sampling, or which appear from their shape, coloration, etc. to be foreign material.

##### 4.2.6.2 PARTICLE BOUNCE

The "D<sub>50</sub> product" guidelines elsewhere are intended to prevent a situation where bounce could be a problem. Visual inspection, however, is always necessary. Bounce can occur even when stages are not overloaded. Bounce occurs when the collection plate substrate material fails to capture and hold a particle that strikes its surface. If bounce has occurred the most direct indication is the filter. The filter loading will be very high and observation with a 10x ocular will show the presence of particles much larger than the D<sub>50</sub> of previous stages. When bounce occurs it is usually a substrate problem, meaning that a different substrate material must be used or the D<sub>50</sub> products of the stages must be reduced by sampling at a lower flow rate. Sometimes the same end result can occur from scouring due to excessive jet velocities. The D<sub>50</sub> product

guideline used in the impactor flow rate/stage selection section will indicate those cases where a different jet stage or impactor flow rate should be selected.

#### 4.2.6.3 OVERLOADING

The maximum individual stage loading which should be permitted (excluding the precollector and filter) is 15mg. The impactor is normally operated in a horizontal mode, consequently captured particulate may fall away from the substrate and migrate to some other part of the impactor unless the substrate material holds the particulate in place. Greased substrates normally work well for this purpose. Matted materials such as quartz or fiberglass will trap the particulate in the fiber mat. Visual observations can provide some indication of whether the "capture" ability of the substrate material has been exceeded. If so, such a run is in question and subsequent runs should sample for shorter durations.

#### 4.2.7 MULTIPLE SAMPLING RUNS

Multiple impactor runs are required to characterize a given test condition (inlet, outlet etc.). Cascade impactors are labor intensive instruments with typical run times of two to six hours (at the outlet of a high efficiency control device). The cost per run is quite high, yet if results are to be believable, multiple runs must be performed. The absolute minimum number of good runs is three. This does not include the mandatory blank run or the exploratory initial run. The recommended minimum number of good runs is five since these two additional runs decrease the width of the confidence interval at the 95% confidence level to about ½ the interval for three readings (a 50% gain in confidence). To obtain an additional 50% gain over the three run confidence interval (50% decrease in the width of the confidence interval associated with the five runs) one would need to make a total of about 14 runs. Admittedly 14 runs is impractical. Seven runs is reasonable and yields roughly one-half the benefit of increasing the number of runs from 5 to 14. For this reason five good runs is the recommended minimum, seven is desirable, while three is the absolute minimum requirement. If, as described in Section 4.2.7, a skewed velocity profile requires multiple regions (multiple runs)... to complete a full traverse, the number of runs must be multiplied by the number of regions. The rationale for requiring a minimum of three traverses and recommending seven is outlined in Appendix D. (Estimations of the uncertainties Associated with Cascade Impactor Data and in Measured Fractional Efficiencies of Control Devices.

The computer program documented in Manual Appendix A has provisions for averaging multiple runs performed at the same test conditions (location, plant load, etc.). Spline curve fitting techniques are applied to the cumulative mass data from each individual run. Averaging and all additional analysis is then performed using only the fitted coefficients for this set of common diameters.

The outlier analyses which can be performed in the averaging process may allow some use to be made of data from runs which might otherwise have to be rejected. Data in individual size ranges of a run which might be affected by gross weighing errors, nozzle



scrappings, etc. will probably be rejected by the (optional) outlier analysis if the data from several runs are being combined.

#### 4.2.8 ANALYTICAL BALANCE PROTOCOL

Two potential moisture related problems may be encountered as one tries to determine accurate pre-run and post-run weights for impactor runs. One is that any moisture accumulated on the substrate (filter) during sampling should be removed and the second is that at some industrial sources the particulate collected (or condensed) during the run may act as a desiccant. Thus even though we remove all the moisture accumulated during sampling this hygroscopic particulate may gain weight upon exposure to room air. The amount of such weight gains depends on the relative humidity of the room air, exposure time, amount of such particulate on the substrate (filter), and hydroscopic propensity of the particulate. In cases where sulfuric acid was collected, the hydroscopic propensity of the acid was stronger than the drying agent in the desiccator and the substrate (filter) gained weight when placed in the desiccator. The use of a spot check second weighing at the end of a second desiccation period serves to verify that moisture uptake has not occurred during desiccation and that the substrates were sufficiently dry at the time of the first weighing (pre-test and post-test). A second moisture uptake test is recommended to determine uptake from room air prior to weighing. If this test shows significant uptake, steps must be taken to minimize exposure to moisture laden air. One step is to remove a single substrate (filter), place it in the weighing chamber (containing a small disk filled with desiccant) and complete this weighing before removing a second substrate from the desiccator. This "one at a time" technique is cumbersome but does minimize the exposure of the substrate to undesiccated air. If the lab has controlled 50% humidity, this technique is probably not necessary but if the lab humidity is high this may well be necessary. This "one at a time" technique should be used unless a test is performed where a complete set of substrates (with filter) is weighed one at a time in an undesiccated weighing chamber after various amounts of exposure time to room air. If the results of such a test show that moisture uptake from room air is not a problem, then and only then should one remove an "entire set at a time" from the desiccator.

#### 4.2.8.1 PRE- AND POST-TEST DESICCATION (Table 4)

Table 4  
Desiccation of Substrate Sets  
(Pre-test and Post-Test)

1. Substrate sets should desiccate for approximately 6 to 12 hours immediately prior to the first weighing (Pre-test and post-test).
2. A small tray of fresh desiccant should be placed in the weighing compartment of the balance (to prevent moisture uptake during weighing) and the exposure of the substrate (filter) to undesiccated air should be minimized unless a moisture uptake test shows that exposure to room air does not result in significant weight changes. This test is made by performing multiple weighings on the same substrate after different amounts of exposure time to room air. Weighing procedures are given in Table 5.
3. The substrate set should desiccate for a second 6-12 hour period before the second weighing. This second weighing may be a spot check unless the difference between the two weighings is greater than 0.05 mg. Second weighings should always be performed on the filters and on post-test weighings of the precollection (and most heavily loaded) substrates.
4. If the difference between the first and second weighings is greater than 0.05 mg, a third weighing should be performed after further desiccation.

Each sample to be weighed should be desiccated to a constant weight, with periodic checks to establish constancy. Hard, nonvolatile particles may be dried in a convection oven at 100°C (212°F), then stored in a dessicator until they cool to room temperature. Weigh them, then check-weigh them 2 hours later. Volatile particles present special problems which have to be dealt with according to the characteristics of the particulate matter and the sampling goals. One technique that has been used for particles which are volatile at elevated temperatures is to dry them in a dessicator 24 hours at room temperature before weighing. Whatever the technique, constant weight of the samples after further drying is the criteria which is normally to be used. Record the results of the weighings (Figure 11, Example Weight Sheets) and any notes in a notebook.

Occasionally samples are collected which are inherently unstable in weight. This can occur if the collected particulate matter is reactive, if it is so hygroscopic that it continues to absorb water even in a conventional desiccator, or if it contains a component sufficiently volatile at room temperature to evaporate during the desiccation period. For these situations special weighing protocols may have to be devised using insight into the nature of the offending process. For example, one may deal with steady loss of

volatile components by immediate “warm” weighing of the real and blank substrates followed by periodic reweighings to establish an estimate of the dry, “time zero” weight. Similar techniques or improved dessication techniques may be used with hygroscopic weight gains. Occasionally it has proven useful to chemically alter a hygroscopic component. In particular, neutralization of sulfuric acid by exposure to trace amounts of ammonia vapor may allow otherwise weight-unstable substrates to be dried to a stable weight.

#### 4.2.8.2 BALANCE OPERATIONS (Table 5)

On some impactors such as the UW Mark 5, the inlet throat serves as the first jet stage. The  $D_{50}$  of the precollector is frequently close to, or perhaps smaller than, that of the first stage. The minimum stage  $D_{50}$  ratio should be 4:3 ( $\times 1.3$  or  $\log D = 0.124$ ). For stage  $D_{50}$ 's more closely spaced, the weight change on the lower stage tends to be affected too much by the lack of sharpness in the collection efficiency of the upper stage (see Manual, Section 2 – Theoretical and Empirical Basis for Cascade Impactors). For this reason if the  $D_{50}$  of a stage is too close to that of an adjacent stage its weight is combined with that of the next lower stage and it is omitted from the analysis. If the  $D_{50}$  of the precollector is less than that of the first stage, the weight change of the first stage provides a measure of the reentrainment from the precollector. The weight sheet records record the individual weights, these are combined by the computer program options described in Manual, Appendix A.

As shown in Figure 11, the filter, foil pouch, and two Teflon insert rings are weighed as an assembly rather than individually. The blank filter and two Teflon insert rings marked “BF” are also weighed as an assembly. The weight sheet (Figure 11) provides a section for recording washdown weights and a description of the tare weights used. The check marks on Figure 11 indicate that the reproducibility criteria were satisfied for the control weight, blank substrate, and blank filter as specified in Section 7.1 (Acceptable Results).

## Table 5

### Balance Procedures for 1/100 mg Analytical Balance (see also Figure 11 Example Weight Sheet)

Note: The procedures listed in this table are generic and should be considered minimal. Modifications should be made as appropriate for a specific vendor's model number.

#### A. Precautions

1. Calibration and tare weights should be handled with smooth edged tweezers. These tweezers should not be used on substrates.
2. When substrates are weighed, check to make sure the substrate is not touching the side of the weighing chamber.
3. Door to weighing chamber should be kept closed except when changing substrates or weights.
4. To protect tare weights, the boxes containing these weights should be closed. Tare weights must be protected from dust and lint.
5. Balance and weighing chamber should be equilibrated in temperature with their surroundings to avoid thermal drift of the zero and scale factor (calibration dial). Room temperature in the weighing room should be regulated to less than 85°F and maintained at this temperature  $\pm 5^\circ\text{F}$  throughout the weighing session. Wide swings in temperature can be advertently affect accuracy.
6. Adequate warmup time must be allowed to assure electrical stability (10-30 min.) and thermal stability. It is best to allow the balance to remain in a power on (standby) mode for days before and during a test. Be sure that sunlight does not shine directly on the balance weighing chamber.
7. Place a small dish filled with indicating type silica gel (desiccant) inside the weighing chamber. Be sure this dish does not interfere with the pan movement.

#### B. Weighing Procedures

1. Check to make sure electrical tare indicator is off.
2. Range dial should be set to 200 mg range.
3. Check zero. If readout does not indicate 00.00, adjust coarse and fine zero dials until the readout is 00.00.

4. Remove 200 milligram calibration weight from container with smooth edge tweezers and place on weighing pan.
5. Allow balance sufficient time to equilibrate. If readout is not 199.99 adjust with calibration dial. This adjustment sets the scaling factor.
6. Record calibration and zero data to balance log book along with date and time.
7. Weigh each tare weight and enter this data in the balance log book. The 50, 100, and 200 mg tare weights should be weighed (without tares). The two 500 mg tare weights should be weighed with the 100 mg and 200 mg weights used as tares.
8. If extreme changes (0.05 mg) in the weights of the tares are noted, the zero and calibration of the balance should be checked and these values, along with any adjustment, should be noted in the log book. The tare weights should then be reweighed as described above. The problem can be that one of the tare weights is dirty and needs to be cleaned.
9. After the tares are weighed, the zero should be rechecked and recorded in the log book, along with any required adjustment.
10. Remove the first substrate from the desiccator. These should be weighed "one at a time" to avoid moisture uptake.
11. The entire control weight set, A through D, should be weighed as part of the first substrate set. These weights should be recorded on the control set weight sheet in the balance log book as well as on the weight sheet.
12. The zero should be checked and recorded, along with any adjustments, each time tares are changed and between substrate sets (as shown on the weight sheet).
13. After the first substrate set is weighed, only control weight C need be reweighed with each subsequent set. If an extreme change in the weight of the control occurs, the zero and calibration of the balance should be checked. The entire control set should then be reweighed. If the weight change is still occurring, check for a dirty tare on control (clean if found) and reweigh each tare. Proceed with the weighing of the substrate sets only when this problem has been corrected.
14. Unless weight changes requiring recalibration of the balance occur, the calibration only needs to be checked every two hours.
15. When the weighing session is concluded, the balance zero and calibration should be checked a final time. Do not turn the balance off. Power should only be

turned off when all weighings for the field test have been completed. This avoids long delays as the balance warms up and obtains thermal stability.

## 5. CALIBRATION

One central laboratory/on-site log of all calibrations should be maintained. Entries from this log should be posted in the equipment maintenance records. The following paragraphs describe the calibration procedures for the instrumentation used with cascade impactors.

### 5.1 PITOT TUBE

As shown in Figure 1 a pitot tube is not used as an integral part of the impactor sampling train. At many commonly encountered flow rates, the presence of the precollector could result in a flow interference at the pitot head causing its coefficient,  $C_p'$  to differ from the baseline value even when the pitot tube is dimensioned as described in Method 2. This interference is dependent on nozzle size and stack velocity. For this reason the pitot is omitted from the sampling train.

A separate Method 2 Pitot Probe is used to measure the velocity profile at various times during a test program. This probe and its components should be calibrated per Section 4 of Method 2.

### 5.2 PRECOLLECTOR NOZZLE

Each nozzle shall be permanently and uniquely inscribed with an identification number. All calibrations and maintenance repairs shall reference this number. Each nozzle shall be inspected and calibrated before initial use. If nicks, dents, or corrosion are discovered, the maintenance logs shall be noted, the nozzle repaired and recalibrated as described below. Figure 12 is a data form that may be used for this purpose. A micrometer capable of measuring inside diameters to the nearest 0.025 mm (0.001 in.) shall be used to make three measurements of the inside diameter of the nozzle (undamaged nozzles only) each on a different axis as shown on the form. The average of these three measurements is then calculated. The difference between the high and the low numbers should not exceed 0.1 mm (0.004 in.).

### 5.3 DRY GAS METER

Wet test meter calibrations of the Dry Gas Meters are performed prior to initial use, and later as required, by comparison to a "standard" dry gas meter. After each field use the calibration of the metering system shall be checked by comparison to a standard dry gas meter as described in Section 4.3 of Method 5. Leak checks shall be performed as described in Section prior to any calibrations or comparisons.

The maximum acceptable leak rate (pump warm and running) is 0.00057 m<sup>3</sup>/min (0.02 cfm) for systems to be used at flows higher than 0.02 cfm. For low flow rate sampling

situations (flow rates 0.2 cfm) the leak rate should not exceed 0.00014 m<sup>3</sup>/min (0.005 cfm). Leaks producing rates greater than these should be repaired before calibration. If leakless pumps suitable for low flow rate operation cannot be obtained, it may be necessary to place the pump downstream of the gas metering system. The field setup programs described in Manual Appendix A make provision for this configuration.

Calibration procedures using a wet test meter are described in APTD-0576. Note—If the dry gas meter coefficient values obtained before and after a test series differ by more than 5 percent, the test series shall either be voided, or calculations for the test series shall be performed using whichever meter coefficient value (i.e., before or after) gives the lower value of total sample volume.

#### 5.4 ORIFICE FLOW METER

Calibration of the metering system orifice flow meter is described in Section 4.3 of Method 5.

#### 5.5 DIFFERENTIAL PRESSURE METER

Calibration of the metering system Differential pressure meter is described in Section 2.2 of Method 2.

#### 5.6 TEMPERATURE DEVICES

Calibration of the temperature metering system is described in Section 2.3 of Method 2.

#### 5.7 BAROMETER

Calibration of barometers is described in Section 2.5 of Method 2.

#### 5.8 GAS DENSITY DEVICES

Calibration and operation of the molecular weight determination equipment (Fyrite analyzer) is described in Method 3.

#### 5.9 IMPACTOR STAGE CONSTANTS

As described in Manual Section 2.4 (Verification of Impactor Theory) normal treatment of field data is to use stage impaction constants calculated from the modified Marple theory rather than stage constants determined during laboratory calibration. The focus of laboratory impactor calibrations has been to validate the theory over a wide range of variations in each of the important parameters used in the model. The significance is that only impactor designs which have been validated by laboratory calibration should be used. Manual Appendix B lists commercially available impactor designs which have been validated together with the physical parameters (stage geometry constants) used by the computer program of Manual Appendix A to calculate the theoretical stage

constants for the given test conditions of temperature, pressure, gas composition, particle density and impactor flow rate. Stage geometry constants are: number of holes, average hole diameter, and jet-to-plate spacing (distance). In the data reduction program, MPPROG, the stage impaction constants,  $\overline{VP50}$ , are designated as SI (i). It should be noted that program MPPROG requires the operator to select either theoretical or fixed calibration values (manually entered in the program DEF/IMP for the impaction constants  $\overline{VP50}$ ). Selection of theoretical calibration values also incorporates adjustments to the stage constants due to particular type of substrate material used (bare metal, coated metal, or fibrous matt). Choice of impactor flow rate and stage selection should be such that the Reynolds number (Re) is greater than 50. Calibrations have shown the theory to be questionable for some jet configurations at Re (50).

#### 5.10 ANALYTICAL

The operating procedures for the analytical balance (Section 4.2.8) provide for frequent calibration using Class S standard weights traceable to the National Bureau of Standards.



Figure 11 Example of a completed Weigh Sheet.

SUBSTANCE SET NO. I 23 DATE OF INITIAL WEIGHING 1 4-10-84  
 :  APIEZON H DATE OF INITIAL WEIGHING 2 4-11-84  
 FIBERGLASS  BARE DATE OF FINAL WEIGHING 1 4-21-84  
 MERC. POLY.  OTHER DATE OF FINAL WEIGHING 2 4-22-84

WASH DOWN

$C_a = 5 \times 10^{-6} \text{ mg/ml}$

SOLVENT  ACETONE  DISTILLED WATER

PRECOLLECTOR NOZZLE AND BODY:

EVAPORATOR DISH:  
 ID I 23 N  
 INITIAL Wt (mg) 416.72  
 FINAL Wt (mg) 420.16

$\Delta$  (mg) 3.44  
 WASH VOLUME (mL) 156 ml  
 RESIDUE,  $W_{aT}$  0.0008

CORRECTED WASH WEIGHT 3.44 mg

PRECOLLECTOR EXIT TUBE AND SOLID DISK:

EVAPORATOR DISH:  
 ID I 23 T  
 INITIAL Wt (mg) 418.53  
 FINAL Wt (mg) 419.23

$\Delta$  (mg) 0.70  
 WASH VOLUME (mL) 161 ml  
 RESIDUE,  $W_{aT}$  0.0008

CORRECTED WASH WEIGHT 0.70 mg

(ADD THESE WEIGHTS TO THE DRY WEIGHTS TO GET TOTAL WT GAIN)\*

DESCRIPTION	ID NO.	INITIAL		FINAL		TOTAL WT. GAIN (mg)		
		TARE (mg)	1 (mg)	2 (mg)	TARE (mg)		1 (mg)	2 (mg)
PRECOLLECTOR	I 23 P	100	30.66	30.69	100	48.79	48.81	21.57*
SOLID DISK	I 23 D	700	4.31	4.29	700	5.16	5.17	1.55*
	ZERO		00.00	00.01		-00.01	00.00	
DISK DONUT:								
CONTROL	CTRL	1050	57.14	57.15	1050	57.14	57.14	✓
S1	I 23-1		58.32			59.98		1.56
S2	I 23-2		53.03			57.87		4.84
S3	I 23-3		65.07	65.05		66.67		1.60
S4	I 23-4		64.06			64.95		0.89
S5	I 23-5		56.87			56.96		0.09
S6	I 23-6		56.02			55.89		-0.13
BLANK	I 23-B	1050	64.91		1050	64.73		(-0.18)
FILTER 1 *	I 23-F	600	53.03	53.01	600	54.06		1.36 ***
FILTER 2 ***	I 23-BF	500	62.01	62.00	500	62.34		N/A
	ZERO		00.01	-00.01		00.00	00.01	

SEE ALSO: (1) LAB LOAD/UNLOAD SHEET  
 (2) OPERATOR'S RUN SHEET

RUN NO. SAMPLE CALC  
 DATE 4-20-84

COMMENTS:

FILTER TYPE:  2500 OAS QUARTZ

- REEVE ANGEL 934AH FIBERGLASS  ACID WASHED ONLY
- GEIAH TEFLON  ACID WASHED AND STACK CONDITIONED
- OTHER  STACK CONDITIONED ONLY

DESCRIPTION OF TARES USED:

* FILTER + 2 TEF. RINGS + POUCH	100 → 100
** BLANK FILTER + 2 TEF. RINGS (BF)	700 → 500 + 200
*** COMBINED WEIGHTS SINCE BF STUCK TO F DURING RUN	1050 → 500 + 500 SS + F
	600 → 500 SS + 100
	500 → 500 5598-11C

C-12

18.13	0.85	1.03
3.44	0.70	0.33
	1.55	1.36



## 5.11 TRIPLE BEAM BALANCE

The lab balance is calibrated using a 50g Class P (or equivalent) analytical weights. After set up in the on-site lab, a silica gel drying column is placed on the balance and the reading is recorded. The 50g Class p weight (1.2 mg tolerance) is added to the drying column on the balance pan and this second reading is recorded. The difference between the two weights must be between: 49.50g and 50.50g.

## 6 CALCULATIONS AND DATA REPORTING

### 6.1 VARIABLES

#### 6.1.1 NOMENCLATURE

Variables are defined as they are used in the equations.

The following paragraphs give equations involved in the setup, operation, and data analysis of cascade impactors. In practice, the calculations are performed by the computer programs documented in Appendix A of this report. Further explanation as to the use of the equations is given in various sections of this report, to include Section 4 (Field Protocol) and Section 5 (Data Reduction and Analysis Procedures).

#### 6.1.2 MOISTURE CONTENT ESTIMATE

An initial guess at the stack moisture is used in the preliminary calculations for stage selection, impactor flow rate, and Target  $\Delta H$  for use with the initial run. Accurate moisture data is obtained during the initial run or by application of Method 4, but an estimate must be made prior to the run. Plant operating personnel will frequently be able to provide stack moisture information. This data may also be available from previous test reports. If necessary, one may use a preweighed drying column and the meter box from the sampling train. Simply record the initial gas meter reading and pull filtered stack gas through the preweighed drying column until the indicating silica gel shows some moisture collection. Record the final gas meter reading and determine the final weight of the drying column. The weight change of the drying column and the gas meter change are used in Section 4.7.13 to estimate the stack moisture.

#### 6.1.3 GAS DENSITY

A Method 3 analysis (Fyrite or Orsat) is used to determine the dry gas volumetric fraction for oxygen ( $O_2$ ) and carbon dioxide ( $CO_2$ ). The preliminary moisture content estimate ( $B_{ws}$ ) is then used together with the  $O_2$  and  $CO_2$  values to calculate the dry mean molecular weight ( $M_d$ ) and the wet mean molecular weight ( $M_w$ ) of the flue gas as follows:

$$M_d = 32B_{O_2} + 44B_{CO_2} + 28(B_{N_2} + B_{CO}) \quad (1)$$

where  $B_{O_2}$ ,  $B_{CO_2}$ ,  $B_{N_2}$ , and  $B_{CO}$  are dimensionless dry volumetric fraction for  $O_2$ ,  $CO_2$ ,  $N_2$ , and  $CO$  respectively.  $M_d$  has dimensions of lb/lb mole. Dry air has a value of 29 lb/lb mole.

$$M_s = M_d (1 - B_{ws}) + 18 B_{ws} \quad (2)$$

where  $B_{ws}$  is the volumetric fraction for water (stack moisture), dimensionless.

#### 6.1.4 POINT VELOCITY

A Method 2 pitot is used to measure the temperature ( $T_i$ ) and velocity pressure head ( $\Delta P_i$ ) at each Method 1 traverse point across the duct. This data is used to calculate the velocity at this point ( $u_i$ ) as follows:

$$u_i = K (\Delta P_i T_i)^{1/2} \quad (3)$$

where

$u_i$  = pitot velocity (ft/sec) at point i,

$T_i$  = absolute temperature at point i ( $^{\circ}R = ^{\circ}F + 460$ ),

$\Delta P_i$  = pitot pressure reading (inches  $H_2O$ ) at point i,

$K$  = pitot-gas composition factor, given by:

$$K = 2.9 C_p (29.92 R'/P_s)^{1/2} \quad (4)$$

where

$$P' = 28.95/M_s \quad (5)$$

$$P_s = P_{bar} + P_g \quad (6)$$

$C_p$  = Pitot calibration coefficient (dimensionless). For a Type S pitot which matches the criteria of Method 2, this coefficient has a value of 0.84. A type S pitot which does not meet the criteria of Method 2 should be calibrated as described in Section 4 of Method 2. A standard pitot is constructed such that it has a coefficient of 0.99,

$M_s$  = Wet mean molecular weight,

$P_s$  = Absolute stack pressure (inches Hg),

$P_{bar}$  = Ambient pressure, barometric pressure at the stack measurement site (inches Hg),

$P_g$  = Stack gauge pressure, differential (=) to atmosphere, (inches Hg, 13.6 inches H<sub>2</sub>O = 1.00 in. Hg). As described in Method 2 this value is measured by disconnecting the downstream side of the pitot tube so that we read the differential between ambient and the downstream side of the Type S pitot. The pitot manometer reads in inches H<sub>2</sub>O so we must convert the  $\pm$  reading to inches Hg by dividing by 13.6.

### 6.1.5 VELOCITY PROFILE

The velocity profile is determined by calculating the velocity at each point of the Method 2 traverse. These point velocities may then be averaged over the whole traverse or over regions of the full traverse (see Section 4.5.3.A.4). The average velocity for the full traverse ( $v_s$ ) and the average temperature ( $T_s$ ) are as follows:

$$v_s = \frac{1}{n} \sum v_i (i = 1, n) \quad (7)$$

$$T_s = \frac{1}{n} \sum T_i (i = 1, n) \quad (8)$$

where n is the number of points in the traverse. The Impactor Traversing Protocol (Section 4.5.3.A.4) gives equations for a division of the Method 1 traverse points into two or more regions, calculation of required sampling velocity for each region, and averaging over only the points in each region.

### 6.1.6 HARDWARE SELECTION

The first decision related to hardware selection is to decide upon the sampler flow rate. Each impactor has a designed range of flows, the exact limits of which depend on stack temperature, viscosity, and the substrate material being used. At outlets one generally desires a high flow rate and at inlets one usually desires a low flow rate. These factors are discussed in Section 4.5.3.A (Preliminary Determinations). When selecting a flow rate ( $Q_i$ ) one is interested in calculating the approximate run time ( $t_{50mg}$ ) associated with this value of  $Q_i$ . An initial guess is obtained by calculating the time required to collect a total sample of 50mg (sum of the precollector, all stage, and filter weights). The following equations are used for this calculation:

#### 6.1.6.1 TIME FOR 50 mg

$$t_{50mg} = 0.77162 / (Q_i G_A) \quad (9)$$

where

$Q_i$  = actual impactor flow rate (ACFM),

$G_A$  = mass loading (gr/ACF).

Note:

$$G_A = 17.65 c_s (1 - B_{ws}) P_s/T_s \quad (10)$$

where

$C_s$  = mass loading (gr/SCF) corrected to standard conditions, (dry, 68°F, 29.92 in. Hg),

$T_s$  = Absolute Stack Temperature (°R = °F + 460),

$P_s$  = Absolute Stack Pressure (inches Hg) as given by Eq. 4-6.

NOTE: 1.00 lb = 7,000 grains = 453.6 gm (gr is the abbreviation for grains)

One should select a flow rate that will allow for reasonable run times, subject to the  $\mu D_{50}$  limits for the selected stages.

#### 6.1.6.2 NOZZLE CHOICE AND FLOW RATE

Only a discrete set of nozzles is available, thus one should modify the selected  $Q_i$  to permit the impactor to be operated isokinetically to the average velocity ( $u_{si}$ ) (over the traverse region  $i$ ) while using one of the real nozzle sizes. The following equations are used for this purpose. Using the flow rate obtained from the  $t_{50mg}$  calculation, calculate an ideal nozzle size then pick a real nozzle close to this size and calculate the corresponding  $Q_i$ . Note different nozzles may be used for the different regions.

$$D_n = 1.748 (Q_i/u_{si})^{1/2} \quad (11)$$

where

$D_n$  = nozzle diameter (inches),

$Q_i$  = impactor flow rate (ft<sup>3</sup>/min)  
actual stack conditions

$u_{si}$  = average velocity over region "i" (ft/sec),

or

$$Q_i = 0.3272 u_{si} D_n^2 \quad (12)$$

To see what  $Q_i$  results when a given nozzle is selected.

#### 6.1.6.3 STAGE CONFIGURATION

The following equations are used to select the stage configuration by calculating the size cut for a given impactor stage, given the stage calibration constant ( $K_s$ ), impactor temperature ( $T$ ), gas viscosity ( $\mu$ ), particle density, and several pressures:

$$D_{50i} = K_s (\mu P_s / Q_i \rho_p P_A C_{i-1})^{1/2} \quad (13)$$

where

$D_{50i}$  = the value of the  $i$ th iteration for the  $D_{50}$  for this stage (cm)

Note: To convert from cm to  $\mu\text{m}$  multiply by  $10^4 \mu\text{m}/\text{cm}$

$K_s$  = stage calibration constant, a function of geometry and substrate materials calculated by the modified Marple Impactor Theory described in Section 2.4,

$P_s$  = local absolute pressure downstream of the stage jet (inches Hg),

$Q_i$  = impactor flow rate ( $\text{cm}^3/\text{sec}$ ),

$P_i$  = absolute pressure at impactor stage inlet (inches Hg). This is the same as the stack pressure,  $P_s$ , less the accumulated pressure drop from the preceding stages.

$\rho_p$  = particle density ( $\text{gm}/\text{cm}^3$ ) determined by helium pycnometer measurements,

$C_{i-1}$  =  $i-1$  iteration for the Cunningham slip correction factor as described below,

$\mu$  = gas viscosity ( $\text{gm}/\text{cm}/\text{sec}$ ) as described below:

The  $D_{50}$  is a function of the Cunningham slip correction factor ( $C$ ) and the Cunningham slip correction factor is a function of the  $D_{50}$ , consequently our approach is to make an initial guess at the Cunningham slip correction factor ( $C_0$ ) and calculate the corresponding value for the  $D_{50}$ ,  $D_{501}$ . This value,  $D_{501}$ , is then used to calculate a new value for the correction factor,  $C_1$ , which is in turn used to calculate a new diameter,  $D_{502}$ . We continue to iterate in this manner until two successive  $C_i$  values satisfy the closeness criteria given below:

$$|1 - (C_{i-1} / C_i)| < 0.001 \quad (14)$$

The equation for the Cunningham correction factor is as follows:

An initial guess,  $C_0$ , is used to calculate  $D_{501}$ , subsequent  $C_i$  using  $D_{501}$  are given by:

$$C_i = 1 + (2L/D_{50i}) [1.23 + 0.41 \text{EXP} (-.44 D_{50i}/L)] \quad (15)$$

where

$D_{50i}$  = diameter (cm) as obtained by using the  $D_{50i}$  equation above and the previously calculated value for C ( $C_{i-1}$ ),

L = mean free path of the gas (cm).

For a stack temperature of 180°C, pressure of 30 inches Hg, and flue gas composition close to that of ambient air the Cunningham correction factor is approximately 1.03 for a  $1 \times 10^{-3}$  cm (10  $\mu$ m) particle and approximately 2.03 for a  $3 \times 10^{-5}$  cm (0.3 $\mu$ m) particle. A good initial guess for C then is  $C_0 = 1.03$ .

For standard air the mean free path (L) (over the range of 0°C to 410°C) is given by:

$$L = (1.04 \mu/P_s) (1 + 0.00367 T)^{1/2} \quad (16)$$

For T (°C),  $\mu$  in (gm/ $\mu$ m/sec) as given below,  $P_s$  (inches Hg), and L (cm).

For standard air the viscosity ( $\mu$ ) (over the range 0°C to 410°C) is given

$$\mu = (174.4 + 0.406 T) \times 10^{-6} \quad (17)$$

For T (°C) and  $\mu$  (gm/cm-sec).

A rigorous algorithm for the calculation of the viscosity of a gas mixture in terms of its components has been given by Wilke (1950). A simplified version for combustion gases has been adapted by Williamson (1983). The simplified version is as follows:

$$\mu = C_1 + C_2 T + C_3 T^2 + C_4 F_{H_2O} + C_5 F_{O_2} \quad (18)$$

$\mu$  = gas mixture viscosity (micropoise),

$F_{H_2O}$  = stack gas moisture fraction (by volume),

$F_{O_2}$  = stack gas oxygen fraction (by volume),

T = absolute temperature of the gas mixture (°R) and for T in °R, the coefficients are as follows:

$C_1 = 51.05$ ,  $C_2 = 0.207$ ,

$C_3 = 3.24 \times 10^{-5}$ ,  $C_4 = -74.14$ ,  $C_5 = 53.15$ .



### 6.1.7 PERFORMANCE CRITERIA

The Reynolds number,  $Re$ , is given by Equation 2-1. In this section the symbol  $u$  will be used to represent jet velocity, not stack gas velocity. The  $uD_{50}$  criteria has units of  $\mu\text{m m/sec}$ . The  $D_{50}$  is given by Equation 4-13 for units of cm. This value must be multiplied by  $10^4 \mu\text{m/cm}$  to obtain the needed units for the  $uD_{50}$  product. The stage jet velocity ( $u_i$ ) is the velocity at each of the jets on stage  $i$  and is given by Equation 4-20 below:

$$u_i = K (P_s/P_i) (Q_A/n_i A_i) \quad (19)$$

where:

$P_s$  = Pressure at the inlet to the impactor. This is the same as the stack pressure (Eq. 4-6),

$P_i$  = Pressure at the inlet to stage  $i$  (Eq. 5-23),

$Q_A$  = Actual impactor flow rate at inlet to impactor, stack conditions,

$n_i$  = Number of holes in stage  $i$ ,

$A_i$  = Average jet area (all jets must have the same nominal diameter) given by the following:

$$A_i = \pi D_i^2/4$$

$K$  = A unit conversion constant

For  $u_i$  (m/sec),  $Q_A$  (ft<sup>3</sup>/min), and  $A_i$  (cm<sup>2</sup>),  $K$  has the value  $K = 4.72$  (m cm<sup>2</sup> min/sec ft<sup>3</sup>)

In terms of  $D_i$  (cm) we have the following:

$$u_i = 3.71 (P_s/P_i) (Q_A/n_i D_i^2) \quad (20)$$

For the above units.

### 6.1.8 TARGET $\Delta H$

The target  $\Delta H$  control parameter ( $\Delta H$ ) is given below. The development of this equation is described by Aldina and Jahnke (1979) in Appendix C of EPA 450/2-79-006 "APTI Course 450 Source Sampling for Particulate Pollutants-Student Manual," December 1979.

$$\Delta H = [846.72 D_n^4 \Delta H_{@} C_p^2 (1 - B_{ws})^2 \frac{M_d T_m P_s}{M_s T_s P_m}] \Delta P \quad (21)$$

where:

- $\Delta H$  = Target  $\Delta H$  control parameter (inches H<sub>2</sub>O),
- $D_n$  = Nozzle diameter (inches),
- $C_p$  = Pitot tube coefficient, Type "S" or standard (dimensionless),
- $B_{ws}$  = Stack moisture fraction as defined above,
- $M_d$  = Mean molecular weight, dry, of the stack gas, as defined above,
- $M_s$  = Mean molecular weight, wet, of the stack gas at the pitot, as defined above,
- $T_m$  = Average absolute temperature of the dry gas meter ( $^{\circ}R = ^{\circ}F + 460$ ),
- $T_s$  = Average stack temperature for this traverse region ( $^{\circ}R = ^{\circ}F + 460$ ),
- $P_m$  = Absolute pressure at the dry gas meter (inches Hg) as described below,
- $P_s$  = Absolute pressure at the stack (inches Hg) as given by equation 4-6,
- $\Delta P$  = Average pitot pressure drop for this traverse region,
- $\Delta H_{@}$  = Orifice meter calibration constant, defined as the  $\Delta H$  which yields 0.75 cfm at 528 $^{\circ}R$ , 29.92 inches Hg, and  $M_d = 29.00$ .

Further explanation is given by the following:

$$P_m = P_{bar} + \frac{\Delta H}{13.6} \quad (21)$$

for  $\Delta H$  in inch H<sub>2</sub>O,  $P_m$  and  $P_{bar}$  in inches Hg

Note: Here we have a term which is dependent on  $\Delta H$  itself. To be rigorous we would need to iterate until a convergence requirement is satisfied. To do this one would calculate  $\Delta H_1$  using an assumed initial value of  $\Delta H_0 = 1.75$ , use  $\Delta H_1$  to calculate  $P_m$  and a new  $\Delta H_2$ , test for convergence then continue iterating until convergence is obtained. In practice, however, this is not necessary because of the small range of  $\Delta H$  values (.1 + 5) and the 13.6 divisor. This type of iterative approach will be required for other

calculations such as the  $D_{50}$  equation and its dependence on the Cunningham correction factor.

Note: For impactor operation a Target  $\Delta H$  control parameter ( $\Delta H$ ) is calculated for each traverse region using the average velocity for the respective regions ( $u_{sk}$ ). The above equation was originally intended for calculation of a  $\Delta H$  for isokinetic sampling at each point in the traverse. Adaptation of this equation to impactor operation (where a constant flow rate is maintained throughout the run) is accomplished by the following equation:

$$\overline{\Delta P_k} = \left( \frac{1}{j} \sum_{i=1}^j \sqrt{\Delta P_i} \right)^2 \quad (23)$$

for all points in region k

thus we have average the square roots of the pitot pressure at each point then square this value.

The basic orifice equation is given below. The development of this equation is described in Appendix C of EPA 45012-79-006 "APTI Course 450 Source Sampling for Particulate Pollutants-Student Manual", December 1979.

$$Q = K \left[ \frac{T \Delta H}{PM} \right]^{1/2} \quad (24)$$

Where Q is the actual flow rate through the orifice, T and P are the absolute temperature and pressure of the gas passing through the orifice, M is the mean molecular weight of the gas and K is a proportionately constant determined by calibration. The value of K is dependent on geometry and choice of units.

Method 5 expresses the calibration constant in terms of  $\Delta H_{@}$  where  $\Delta H_{@}$  is defined to be the pressure drop across the orifice which would result in a flow rate of 0.75 ft<sup>3</sup>/min for dry standard air at 68 °F (528°R), 29.92 in. Hg, and mean molecular weight of 29.0, thus in terms of K

$$\Delta H_{@} = \frac{0.9244}{K^2} \quad (25)$$

Orifice calibration procedures are described in Section 4.6.4 which yield  $\Delta H_{@}$  values for each orifice.

#### 6.1.9 TRAVERSE POINT DWELL TIME

Velocity weighted dwell times are not recommended since all points in any given region are within  $\pm 20\%$  of the sampling velocity (Section 4.5.3.A.4). Equal dwell times are

used for all traverse points in a given Region. Thus the dwell time (t) for each traverse point in a given region is obtained from

$$t = q/n \quad (26)$$

where q = Total Run Time (min),  
n = number of traverse points in a given Region.

#### 6.1.10 AVERAGE GAS METER TEMPERATURE, AVERAGE EMISSION GAS TEMPERATURE, AND AVERAGE ORIFICE PRESSURE DROP ( $\Delta H$ )

The average dry gas meter temperature, flue gas temperature, and orifice pressure drop ( $\Delta H$ ) are calculated using the form shown in Figure 4-7. Figure 4-9 shows example data. The average inlet dry gas meter reading and the average outlet dry gas meter reading are used to determine the average dry gas meter temperature.

#### 6.1.11 DRY GAS METER VOLUME AND LEAKAGE CORRECTION

The sample volume measured by the dry gas meter (DGM),  $V_m$ , must be corrected to normal (or engineering standard) conditions,  $V_m(\text{std})$ , (68°F, 29.92 in. Hg) by the following equations:

$$V_m(\text{std}) = 17.64 (P_m/T_m) V_m Y \quad (27)$$

where

$P_m$  = Absolute pressure at the dry gas meter (inches Hg) as given by Equation 4-22

$T_m$  = Average dry gas meter temperature ( $^{\circ}\text{R} = ^{\circ}\text{F} + 460$ ) as calculate on the run sheet,

$Y$  = Dry gas meter calibration constant,

$V_m$  = Actual sample volume as measured by the dry gas meter ( $\text{ft}^3$ ). Final DGM reading minus initial DGM reading.

If the post-test hot leak check with the sampler removed shows a leak rate in excess of either 4% of the impactor flow rate or 0.02  $\text{ft}^3/\text{min}$  then the run should be rejected. If the leak is less than this value no volume correction is required. If the leak test with the sampler in place showed a leak in excessive of 10% of the impactor flow rate the run is rejected. If the leak is less than the 10% limit (and the "sampler removed" test is less than the limit above) no correction is required because the flow calculated by the dry gas meter reading is correct.

### 6.1.12 VOLUME OF WATER VAPOR

The total moisture catch from the condenser and drying column is calculated on the Run Sheet at position U2 as shown in Figure 4-7 (see also Section 4.5.3.D.5 Instruction for Using the Run Sheet). The Total Volume H<sub>2</sub>O (V<sub>lc</sub>) in mL is converted to vapor equivalent by the following equation:

$$V_w(\text{std}) = [(\rho_w / M_w)(RT_{\text{std}} / P_{\text{std}})]V_{lc} \quad (28)$$

$$V_w(\text{std}) = K_2 V_{lc} \quad (29)$$

where: K<sub>2</sub> = 0.04707 ft<sup>3</sup> water vapor (at 68°F, 29.92 in. Hg) per mL liquid water.

### 6.1.13 MOISTURE CONTENT

The moisture content (B<sub>ws</sub>) is calculated by the following:

$$B_{ws} = V_{w(\text{std})} / (V_{m(\text{std})} + V_{w(\text{std})}) \quad (30)$$

### 6.1.14 ACETONE BLANK CONCENTRATION

Acetone is used to washdown the nozzle, precollector, and connecting tube. This washdown liquid/particulate solution is then evaporated, desiccated and weighed. This weight includes both the weight of the particulate removed by the washdown and the residue (impurities) of the solvent used to perform the washdown. To determine the weight of the particulate alone, we must correct for the residue present in the washdown solvent. The acetone blank concentration (C<sub>a</sub>) is used to make this correction. By measuring the volume of the acetone used to perform the washdown and applying this residue concentration factor (C<sub>a</sub>), we can determine the weight of the residue and subtract this number from the total weight change to determine the weight of the particulate alone.

Approximately 200 mL of the acetone used for washdown is placed in a beaker labeled "Acetone Blank". This solvent is then measured (volume or weight), evaporated, desiccated, and weighed. The acetone blank residue concentration, C<sub>a</sub> (units of mg residue per mL liquid acetone) is then calculated from the following:

$$C_a = m_a / (V_a \rho_a) \quad (31)$$

where m<sub>a</sub> = mass of residue of acetone blank after evaporation and desiccation (mg),

V<sub>a</sub> = Volume of acetone blank (mL),

ρ<sub>a</sub> = Density of acetone liquid (mg/mL). Used to convert between liquid volume and liquid weight. Specified by manufacturer on bottle's label.

Note: Acetone used for washdown must be stored in glass bottles.  $C_a$  is calculated for each separate bottle. For acetone to be acceptable as a washdown solvent the following criteria must be met:

$$C_a \times 100\% < 0.001\% \quad (32)$$

#### 6.1.15 % ISOKINETIC

Calculation of % Isokinetic is the same as with Method 5/17 except that volume corrections are not made for measured leak rates and the average velocity is the average for a given region. This equation is as follows:

$$I = \frac{T_s V_{m(\text{std})} P_{\text{std}} 100\%}{T_{\text{std}} v_s \theta A_n P_s 60(1 - B_{ws})} \quad (33)$$

$$= K_4 \frac{T_s V_{m(\text{std})}}{P_s v_s A_n \theta (1 - B_{ws})} \quad (34)$$

where

- $K_4$  = 0.09450 for English units given below,
- $T_s$  = Absolute Stack Temperature ( $^{\circ}\text{R} = ^{\circ}\text{F} + 460$ ),
- $V_{m(\text{std})}$  = Dry Gas Meter Volume ( $\text{ft}^3$ ) corrected to  $68^{\circ}\text{F}$ ,  $29.92''$  Hg as given by Equation 4-27,
- $P_s$  = Absolute Stack Pressure (in. Hg) as given by Equation 4-22,
- $v_s$  = Average stack gas velocity (ft/sec) for this Region. The average of the point velocities for all points in this region, Equation 4-7,
- $\theta$  = Total Sampling time (minutes),
- $B_{ws}$  = Stack moisture fraction (given by Equation 4-30) for this run,
- 100% = Conversion factor to percentage,
- 60 = Conversion factor, 60 sec per minute,
- $A_n$  = Cross sectional area ( $\text{ft}^2$ ) of the circular nozzle given by:

$$\begin{aligned} A_n &= \pi d^2 / (4 \times 144) \\ &= 0.005454 d^2 \end{aligned} \quad (35)$$

for  $d$  = nozzle diameter (inches),  
144 = conversion factor,  $144 \text{ in}^2 / \text{ft}^2$ .

#### 6.1.16 ACETONE WASH RESIDUE

The weight of residue from the acetone used to perform a washdown must be subtracted from the evaporated/desiccated weight in order to determine the true weight of the particulate removed by the washdown procedure. The weight of the residue is referred to as the acetone wash blank,  $W_a$  (mg), and is calculated by the following:

$$W_a = C_a V_{aw} \rho_a \quad (36)$$

where

$C_a$  = Acetone blank residue concentration as given by Equation 4-31 (mg residue/mL liquid acetone),

$\rho_a$  = Density of acetone liquid (mg/mL). Used to convert between liquid volume and weight of liquid,

$V_{aw}$  = Volume of acetone used to perform the washdown (mL).

This residue weight contribution ( $W_a$ ) is then subtracted from the washdown evaporated/desiccated weight. In no case shall a blank value ( $W_a$ ) greater than 0.001% of the weight of the acetone used for a washdown ( $V_{aw}\rho_a$ ) be permitted (i.e.,  $C_a \times 100\% < 0.001\%$ ).

With an impactor precollector two separate washdowns are performed (1) nozzle, body of precollector, and brush and (2) exit tube of precollector, connecting tube, and brush.

#### 6.1.17 TOTAL PARTICULATE WEIGHT AND BLANK WEIGHT CORRECTIONS

If the blank impactor run shows reproducible weight changes, corrections may be calculated to be applied to the measured stage weight gains. If the weight changes are not reproducible, alternate substrate materials should be selected. Consider the set ( $w_i$ ) consisting of all weight changes for substrates from the Blank Impactor run together with the weight change for the Blank Substrate from each real run. If the range of this set is less than  $\pm 0.25$  mg the set may be considered reproducible and the average for this set should be applied as a correction to all the weight sheet records. Separate blank corrections are determined for the filter using the weight change values from the two filters in the blank impactor run together with the blank filter in each of the real runs. The corrections (substrate and filter) are calculated as follows:

Calculate the average:

$$\bar{w} = \frac{1}{n} \sum_{i=1}^n w_i \quad i=1, n \quad (37)$$

for  $w_i$  = Final Weight (mg) – Initial Weight (mg).

Test for Reproducibility:

$$\bar{w} - c < w_{\min} < w_{\max} < \bar{w} + c \quad (38)$$

where  $c = 0.25$  mg or 10% of the stage catch of the most lightly loaded substrate in real runs; whichever figure is smaller.

If Equation 4-38 is satisfied for the set of all blank substrates (filters) the new weight change ( $\Delta m'_i$ ) is calculated as follows:

$$\Delta m'_i = \Delta m_i - \bar{w} \quad (39)$$

where  $\Delta m_i$  is the weight change for a substrate (filter) and  $\bar{w}$  is as calculated by Equation 4-37 for the appropriate set. One for the substrates and a different correction factor for the filters.

If the values from the blank runs are reproducible but individual runs violate the criteria of Equation 4-38 the outlier tests described in Section 5.4 may be used to selectively reject individual runs. Note that the data from such runs may include substrates where the blank weight change is a small percentage of the change for any given substrate. In such cases, we need only reject those substrates where the blank change exceed 10% of the weight change for this substrate.

The total particulate weight may be calculated by summing all corrected catch weights (precollector, collection stages, filter) and the washdown weights (corrected for the respective wash blanks,  $W_a$ ).

#### 6.1.18 PARTICULATE CONCENTRATION

The stack loading or particulate concentration is calculated from the following:

$$C_s = (0.001 \text{ g / mg})(M / V_{m(\text{std})}) \quad (40)$$

where

$C_s$  = Particulate concentration, dry basis, connected to dry standard conditions (g/dscf) for the above equation,



M = Total particulate weight (mg),

$V_{m(\text{std})}$  = Dry gas meter volume (ft<sup>3</sup>) corrected to standard condition (68°F, 29.92 in. Hg).

Note: The dry gas standard particulate concentration,  $C_s$  may be expressed in different units (the same symbol,  $C_s$  is used). Common units for  $C_s$  are grains per dry standard cubic foot (gr/dscf), pounds per dry standard cubic foot (lb/dscf), and grams per dry normal cubic meter (g/dncm). Conversion factors are as follow:

<u>From</u>	<u>To</u>	<u>Multiply By</u>
ft <sup>3</sup>	m <sup>3</sup>	0.02832
g	gr	15.43
g	lb	$2.205 \times 10^{-3}$
lb	gr	7,000
g/ft <sup>3</sup>	g/m <sup>3</sup>	35.51
gr/ft <sup>3</sup>	gm/m <sup>3</sup>	2.288
lb/ft <sup>3</sup>	gm/m <sup>3</sup>	1.602

The particulate concentration may also be expressed in terms of actual stack conditions, wet. The volume  $V_{m(\text{std})}$  must be converted to stack conditions and the moisture fraction taken into consideration as follows:

$$V_{m(A)} = [T_s / (17.65 P_s)] [V_{m(\text{std})} / (1 - B_{ws})] \quad (41)$$

$$G_A = (0.001 \text{ g/mg}) (M/V_{m(A)}) \quad (42)$$

where

$G_A$  = Particulate concentration at actual, wet, stack conditions (g/dscf),

$V_{m(A)}$  = Volume of the dry gas meter (ft<sup>3</sup>) expressed as actual wet stack gas sampled through the impactor, stack temperature ( $T_s$ , °R), stack pressure ( $P_s$ , in. Hg) and stack moisture content ( $B_{ws}$ ),

17.65 = 528°R/29.92 in. Hg,

M = Total particulate weight (mg) Section 4.7.17.

Note: The wet actual particulate concentration,  $G_A$ , may be expressed in different units (the same symbol,  $G_A$  is used). Common units for  $G_A$  are grains per actual cubic foot, wet (gr/acf), pounds per actual cubic foot, wet, (lb/acf), and grams per actual cubic meter, wet (g/acm).

### 6.1.19 STAGE CUT POINTS

Section 5 (Data Reduction and Analysis Procedures) gives the equations used to calculate the Stage Cut Points. Section 4.7.6 gives the  $D_{50}$  equation (Equation 4-13). Figure 4-5 shows the  $D_{50}$  for various stages of the Pollution Control Inc. University of Washington Mark 5 Impactor at 300°F for dry air at various flow rates. Equation 4-13 in Section 4.7.6 (Hardware Selection) also gives the  $D_{50}$  equation. Optionally, the calculations may be performed by the computer programs described in Appendix A.

## 6.2 DATA FORMS

Data forms used with cascade impactors include Method 2 velocity profile forms (Figure 5 of Method 2), the manual version of the run sheet (lab and field) as shown in Figure 6 and 7, and the weight sheet shown in Figure 11. A run sheet form for use with the computer programs is given in Manual Appendix A, Figure 1. The weight book consists of the completed weight sheet forms (one for each substrate set) together with the balance record book (chronological record of setup checks, zero's, repairs, etc.), controls weight sheet (date, time, and weight values for control A, B, D, and D), and tares "weight sheet" (date, time, and weight values for tares used).

Calibration forms include Figure 12 for nozzles, and Figure 8 of Method 5 for dry gas meter and orifice calibrations using a wet test meter. Manual, Appendix C includes figures which may be used as photocopy masters for all of these forms.

A central record of calibration data and equipment maintenance records should be maintained separately. Appropriate copies should be made from records in this central file and stored with the field test data sheet. A bound notebook providing a chronological record of what happened during a test should also be maintained. This is used to prevent potentially important information from being lost or forgotten. This notebook becomes a part of the permanent test records. It is usually maintained by the leader of the test crew. Files should also be maintained for "other forms" such as velocity traverses, flue gas composition measurements, barometric pressure readings, reports of post-test measurements such as flue analysis (ultimate and proximate for coal, etc.), physical density by helium pycnometer, Bahco particle size analysis of bulk fly ash samples, etc. Other files may be needed for plant data records (load conditions, product feed rates, etc.) and for data reduction computer printouts. Computer printouts to set-up parameters are normally filed with the appropriate run sheets. Data reduction printouts include printouts of both input data and outputs such as tabulated data and graphs. Computer programs often evolve or are modified for various reasons, so it is advisable to maintain diskettes (computer storage media) of both input data and source listings of the data reduction routines so that future questions about "which version of the program was used" may be easily answered.

In summary, the field test data records can be divided into seven sections as follows: (1) chronological record, (2) run sheets (run side and lab side), (3) weight records, (4)

calibration and maintenance records, (5) other forms, (6) plant data records, and (7) computer printouts and diskettes.

### 6.3 REPORTING REQUIREMENTS

Any written reports should include all the appropriate sections used in a report from a Method 5 test such as a description of the plant process, sampling port locations, control equipment, fuel/feed stocks being used, general plant load conditions during the test (descriptions of plant production equipment problems, etc.), and anything else necessary to characterize the condition being tested.

All raw data (weight sheets, run sheets, calibration records, velocity profile data) should be listed in an appendix to the report and the following outputs should be given in a graphical form (tabulated form should be included in the appendix) for the average from multiple runs: (1) Plots of cumulative percent vs. aerodynamic diameter and (2) plots of  $dM/d\text{Log}D$  vs. aerodynamic diameter, and (3) plots of cumulative concentration vs. aerodynamic diameter.

Additional information may be required for any given project. The information listed above is to be considered as the minimum amount that should be included to characterize a given operating condition.

### 6.4 COMPUTER PROGRAMS

Most of the calculations outlined in this report can be performed by the optional set of computer programs given in Manual, Appendix A. This appendix includes complete documentation, operating instructions, and illustrations for the computer programs.

## 7. QUALITY ASSURANCE AND CONTROL

### 7.1 ACCEPTABLE RESULTS

The following criteria are used to determine the acceptability of test results.

#### 7.1.1 GENERAL TEST CRITERIA

##### 7.1.1.1 BLANK IMPACTOR GAINS

Blank Impactor Gains: A blank impactor run is mandatory in order to demonstrate the suitability of the selected substrate material. The maximum recommended range (deviation from the average) in the substrate weight changes for this blank run is 0.25 mg.

#### 7.1.1.2 MINIMUM NUMBER OF RUNS

Minimum number of runs: It is recommended that seven (7) sets (multiple runs synthesizing a complete traverse) be performed. The minimum number of sets that may be used to characterize a condition is three (3).

#### 7.1.2 CRITERIA FOR INDIVIDUAL RUNS

##### 7.1.2.1 REPRODUCIBILITY OF CONTROL WEIGHTS

Reproducibility of Control Weights: The control weights used in the operation of the analytical balance should be reproducible to within  $\pm 0.05$  mg. The precision associated with the stage weight gains is determined by the reproducibility of the control weights.

##### 7.1.2.2 REYNOLDS NUMBER LIMIT

Reynolds Number Limit: The combination of selected jet stage and impactor flow rate must be such that Reynolds numbers are greater than 50. Reynolds numbers greater than 200 are desirable.

##### 7.1.2.3 BOUNCE PREVENTION

Bounce Prevention: The combination of selected jet stage and impactor flow rate must be such that the product of the jet velocity ( $v$ ) and aerodynamic stage cut point ( $D_{50}$ ) does not exceed the following values: for bare metal substrate, 5  $\mu\text{m}\cdot\text{m/s}$ ; for fiber mat substrate, 15  $\mu\text{m}\cdot\text{m/s}$ ; for greased substrated, 25  $\mu\text{m}\cdot\text{m/s}$ .

##### 7.1.2.4 IN-SITU SAMPLING

In-Situ Sampling: Extractive sampling into an impactor is not permitted, even when heat traced lines are used and the impactor is placed in a heated oven. The nature of the problem is that excessive particulate losses occur in extractive probes. The ability of an extractive probe to remove particles of a given size is dependent on flow rate, tube diameter, number of bends, and a host of other factors. Size selective losses occurring in the probe invalidate the data from the impactor.

##### 7.1.2.5 STRAIGHT NOZZLE

Straight Nozzles: Only straight nozzles may be used. Method 5 type goose neck (button hook) or other 90° bend nozzles may not be used. The impactor must either be rotated into the gas stream so that a straight nozzle can be used or a right angle precollector should be used to permit the impactor to be operated perpendicular to the direction of the gas flow.

#### 7.1.2.6 MINIMUM NOZZLE DIAMETER

Minimum Nozzle Diameter: The primary problem associated with the use of small nozzles is pluggage of the nozzle by large particles. For this reason, 1.4 mm is recommended as a particle minimum nozzle ID. In practice, however, a smaller nozzle may be used if one is willing to accept the increased risk of a nozzle pluggage. A secondary problem may be a shift of the  $D_{50}$  of the entry stage to the system (i.e. precollector or the first impactor stage depending upon the configuration).

#### 7.1.2.7 IN-SITU HEATING

In-Situ Heating: If the stack temperature is above 347°F (175°C), sampling may usually be performed at stack temperature. At stack temperatures less than this limit, it may be necessary to heat the impactor to at least 18°F (10°C) above the stack temperature by the use of external heaters wrapped around the impactor. The decision to externally heat the impactor depends primarily on the properties of the flue gas. Thus, high moisture stacks or high SO<sub>3</sub> levels may require in-situ heating of the impactors. The postrun visual examination of the impactor substrates will indicate the presence or absence of condensation problems.

#### 7.1.2.8 WARM-UP REQUIREMENT

Warm-Up Requirements: Warm-up times should be 45 minutes to one hour. Shorter times may result in condensation occurring on various surfaces of the impactor.

#### 7.1.2.9 MINIMUM RUN TIME

Minimum Run Time: The shortest permissible run time is 60 seconds. A desirable minimum run time is three minutes. If high loadings require run times shorter than 60 seconds, a lower flow or different sampling device should be used if possible. Great care must be taken when operating with such short run times.

#### 7.1.2.10 LEAK TESTS

Leak Tests: The impactor must satisfy both the pre-test hot leak test criteria and the post-test hot leak test criteria given in Table 1.

#### 7.1.2.11 ANISOKINETIC SAMPLING LIMITS (POINT)

Anisokinetic Sampling Limits: At each traverse point sampled during a given impactor run, the point velocity ( $v_i$ ) must be within  $\pm 20\%$  of the inlet velocity ( $v$ ) for the impactor, thus  $.8v \leq V_i \leq 1.2v$ .

#### 7.1.2.12 NOZZLE INSPECTION

Nozzle Inspection: The nozzle must pass the post-test nozzle damage visual check.

#### 7.1.2.13 SUBSTRATE INSPECTION

Substrate Inspection: When the impactor is unloaded, the stage catches are inspected to see if overloading, scouring, bounce, condensation, handling losses, etc., have occurred such that the data are compromised or invalidated.

#### 7.1.2.14 ISOKINETIC REQUIREMENT (RUN)

Isokinetic Requirements: The calculated % Isokinetic (I) for a given run must satisfy the following:

$$75\% \leq I \leq 125\%$$

(as calculated by Equation 34).

#### 7.1.2.15 MAXIMUM STAGE LOADINGS

Maximum Stage Loadings: Excluding the precollector and filter, the individual substrate catch should not exceed 15 mg. If this limit is exceeded one runs a risk of overloading the substrate. The actual point where overloading occurs depends on the design of the impactor used, the type of substrate material selected, and the properties of the material collected. The postrun visual examination is the best check for overloading. Other tests include unrealistic filter weight changes and microscopic examination of the filter and substrates for the presence of grossly oversized particles.

#### 7.1.2.16 BLANK SUBSTRATE WEIGHT CHANGES

Blank Substrate Weight Change: The recommended range in weight changes for the blank substrate is 0.25 mg (or 10% of the expected weight change for the loaded substrates). The weight change of the blank substrate provides a cumulative measure of all balance errors (drift in the analytical balance), handling losses, flue gas-substrate interactions, etc., that might affect the weight change determinations for an impactor run. The change for each run should be compared to the grand average of all other blank substrates ("blank" impactor run and blank substrate from each real run). Any given run is suspect if its change is significantly different (an outlier) from this grand average. Any temporal variations in the substrate flue gas interactions can be detected by use of the blank substrate in each run. The outlier tests described in Section 5.4 may be used to reject individual runs.

#### 7.1.2.17 BLANK FILTER WEIGHT CHANGES

Blank Filter Weight Change: Some criteria as above except that the criteria are applied to the set of all blank filter weight changes rather than the set of all blank substrate weight changes.

## 7.2 SPECIAL CONSIDERATIONS

There are a number of problems inherent in cascade impactor sampling which could result in the invalidation of whole sets of data. The intent of this section is to outline measures, which if integrated into standard impactor operating procedures, would reduce these potential errors to acceptable levels.

### 7.2.1 PRETEST SITE SURVEY

Some prior knowledge of the test site and flue gas conditions is required for efficient test preparation. One method of obtaining the necessary information is a pretest site survey by one or two experienced individuals.

The goal of the survey is to gather information needed by the sampling crew for adequate planning of the test. The minimum data required are the identification of special or unusual problems so that work can begin on tasks which must be completed prior to testing (such as installation or enlargement of ports). Usually, the more complete the survey, the more efficient and worthwhile the testing will be.

In cases where the sampling crew is unfamiliar with both the site and the type of process stream to be sampled, data concerning the process itself should be collected during the pretest survey. It is important to ensure that enough information is available so that sampling can be performed under typical operating conditions, particularly if a batch or cyclical process is to be tested or if the source is occasionally operated in an anomalous mode. Other important plant information includes availability of facilities and supplies such as electrical power, water, ice, and laboratory space. An additional aspect of the plant survey which must not be neglected is a thorough safety inspection.

In addition to the plant data mentioned above, a site survey should include careful annotation of gas stream conditions expected at the sampling points. Information concerning gas temperature, pressure, composition, and approximate particulate loading will be needed to select the optimum equipment and sampling strategy. If possible, an impactor should be operated during the survey to identify potential problems. Such a test can be valuable in the determination of mass loading, proper sampling duration, and collection substrate and impactor suitability.

The precision of testing performed during a survey should not be expected to equal that of the actual test, but it should be close enough so that problems that might be encountered in the actual test can be anticipated from the results of the survey. This will make decisions regarding the correct equipment and techniques possible. If a pretest survey is not possible, it may be necessary to use the first impactor runs of the test series as "trash" runs to provide information for the proper setup of the remaining test runs.

In situations where the source is of a type previously tested and sampling conditions at the site are familiar to the sampling team, only a site inspection may be needed. This

visit should be made by a member of the sampling team who should establish contact with plant personnel, inspect sampling ports for size, location, and suitability, request needed items or work (such as port enlargement or replacement, sampling platforms, laboratory space, and electrical power), and identify sources of possible problems. Port size, port extension, inside duct dimensions, and port adapter configuration can be determined with a tape measure. Generally, the pretest site inspector should look for unusual problems or circumstances that will need attention before the test date.

### 7.2.2 CYCLIC PROCESSES

As previously mentioned, cyclic processes can introduce greater difficulty into a sampling program. The test procedure should be planned and coordinated with plant personnel so as to span an integral number of process cycles, if possible.

### 7.2.3 SUBSTRATE COLLECTION SURFACE

Extensive studies of substrate media have shown that suitable substrates exist for most applications if caution is exercised in selection and use. It should be noted that impactor calibration and performance depend upon the type of substrate used and that calibration is required for each type. Also, the stability of the substrate should be checked in each gas stream being sampled. Both greases and glass fiber mats typically experience anomalous weight changes when exposed to stack gases.

The pretest survey should include a series of blank impactor runs to aid in the selection of the substrate material. A good rule of the thumb is that the maximum allowable change in weight of the blank substrate should be no more than 10% of the mass of the particulate matter that is expected to be collected on the impactor stage collecting the least mass. In most instances, a blank substrate weight change of 0.25 mg is excessive. Reproducibility of blank weights is of greater concern than the absolute magnitude of the change. If the changes are reproducible, corrections for them can be made to the data with confidence that valid results will be obtained.

### 7.2.4 IMPACTOR JET STAGES

Most commercially available impactors come with a fixed set of stages which are used at all times and no decision as to which stages to use is required. However, in some cases, most notably the University of Washington Mark V impactor, a variety of jet stages are available and those most suited to the sampling conditions to be used.

A trade-off exists between three major considerations when choosing jet stages. Because of the non-ideal behavior of jet stage efficiency curves, a separation should not be smaller than about a factor of 1.5. Excessive jet velocities can result in low Reynolds numbers and uncertainty in the value of the impaction parameter.

If data regarding a particular particle diameter are desired, the cutpoint of two stages should bracket this diameter for reliable interpolation of the mass less than this



diameter. If the target diameter is large, the cutpoint of the largest stage should be as close to the desired diameter as possible to reduce extrapolation errors.

#### 7.2.5 SMALL NOZZLE SIZE

The particle size cuts of cyclones and impactors are dependent on a number of factors. Other than the selection of stages, the sampling flow rate is the only variable affecting the cut sizes which can be adjusted by the user. If a multi-stage device is used to measure the complete size distribution, some latitude is available in setting the flow because interpolation can be used to determine the concentration of particles in any designated size range within the operating limits of the sampler.

If a given stage is required to produce a stated size, say 10  $\mu\text{m}$ , the sample flow rate required to obtain that cut will be dictated by the sampler used (given the gas composition and temperature of the process stream being measured). This means that if a cut at a specified target diameter must be obtained, one may not have the latitude in selecting the sampler flow to be used that one has in simple total particulate measurements or even for standard impactor runs. The matching of the sample inlet velocity with the gas stream velocity for isokinetic sampling must be accomplished entirely through the cross-sectional area of the sampling nozzle. This means that a much larger array of nozzles must be available than those used in Method 5 sampling. If the isokinetic error is no larger than 20%, the maximum error in the measured emission rate of 10  $\mu\text{m}$  particles will be about 15% and the errors for smaller particles will be lower. Errors for large particles will be approximately equal to the isokinetic error. Deviations of 20% from isokinetic can probably be tolerated. If sampling is to be done within 20% of isokinetic, an array of nozzles must be available that step by 10% in diameter from one to the next.

Once the flow rate is determined, it can be used with the gas velocity to select the appropriate nozzle to use. Only straight nozzles should be used as "gooseneck" or bent nozzles will, in most cases, severely perturb the results.

If there is no requirement for a specific size cut as may be required in  $\text{PM}_{10}$  sampling, the operator has more flexibility to choose a flow rate suitable to the requirements of his sampler and the particulate loading of the gas stream. Typically the average velocity of the points to be traversed is determined using EPA Method 2. Next a nozzle is selected whose isokinetic flow rate at this average velocity is judged to be suitable for the particular site and impactor. The flow rate determined in this way is maintained at all sampling points on the traverse. If the velocity distribution is poor, several runs may have to be made, each covering a part of the duct, to synthesize a complete traverse.

The flow rate mentioned above is considered to be suitable for a particular impactor if it falls within the recommended operating limits of the impactor and restricts bounce and reentrainment of particles.

Studies have been conducted which have supplied the following operating criteria which, if met, may be expected to yield acceptable impactor samples:

1. If bare metal substrates are used, the  $vD_{50}$  products should not exceed 5  $\mu\text{m}\cdot\text{m/s}$ .
2. If glass or quartz fiber substrates are used, the  $vD_{50}$  products should not exceed 15  $\mu\text{m}\cdot\text{m/s}$ .
3. If greased substrates are used, the  $vD_{50}$  products should not exceed 25  $\mu\text{m}\cdot\text{m/s}$ .
4. The spacing between the  $D_{50}$ 's of adjacent stages should not exceed a factor of about 2.5. If this spacing is exceeded, particles having momenta too high for reliable collection will be passed to the succeeding stage.
5. Operation at flow rates which result in very low Reynolds numbers should be avoided.

These are very generalized guidelines and should not be considered as hard and fast rules for all situations. The properties of the particles (e.g., hard dry particles or sticky particles) may dictate some modification of these criteria. An impactor run during the pretest site survey is recommended to properly assess these considerations.

The time required to collect an adequate sample depends on the mass loading of the aerosol, the size distribution of the particles, and the gas flow rate in the sampler. If the results of a mass test are available, the mass loading can be obtained from them. If not, an estimate should be made based on the pretest survey or other information. Given the mass concentration, an estimate of the sampling time for initial tests can be obtained from nomographs. Results from the initial tests can then be used to more accurately establish the optimum sampling time.

The amount collected on each stage also depends on particle size distribution. If the flue gas contains mostly large particles, the precollector and upper stages of the impactor will contain more particulate matter than the filter or the lower stages. Two conflicting criteria complicate the choice of the sampling time. It is desirable, for minimizing weighing errors, to collect several milligrams on each stage, however, most size distributions are such that the upper stages are overloaded and particles become entrained before the lower stages collect as much as a few milligrams. A rule of thumb is that no stage should be loaded above 15 mg, but the determining factor is whether or not reentrainment occurs. The deposit on each stage must always be visually observed to judge the "quality" of the deposits and the appropriate sampling time.

## 7.2.6 CALIBRATIONS

In most projects involving impactor sampling, the accuracy, precision, and comparability of gas volume and flow rate measurements are critical to the project data quality

objectives. For this reason the flow metering system of each sampling train should have dependable calibrations. A pretest calibration check of the dry gas meter and orifice, using the procedure outlined in EPA Method 5 for post test calibration checks, is suggested but not required. This is especially true if the system has not been used for an extended period of time.

The type S pitot tube should be calibrated prior to testing according to the procedure in Method 2. All temperature sensors in the system should be checked for proper calibration using the procedures outlined in Method 5.

### 7.3.7 ON SITE OPERATIONAL CHECKS

There are a number of in-field checks of the sampling system that can be performed to ensure the quality of data collected. Although the procedures outlined below cannot detect all possible problems, the suggestions listed can help eliminate several sources of error. One operational check that should never be neglected is a leak check of the entire sampling train. This is best done in three steps: the assembled collection device only, the sampling train without the collection device, and the sampling train with the collection device mounted on the probe.

The procedure to leak check the impactor should be performed after the impactor is loaded and assembled. If a precollector is to be used, this should be attached to the impactor and the whole assembly leak checked as a unit. The inlet to the collection device should be plugged and the outlet attached to the suction side of a small pump. The vacuum side of a mercury manometer or vacuum gauge should be connected in parallel to the impactor with the positive pressure side open to ambient. The pump valving should be adjusted until the manometer registers a vacuum of approximately 11 inches Hg. The impactor should then be sealed off. Field use of this leak check procedure has indicated that impactor assemblies experiencing pressure losses of less than 5 to 6 inches Hg in 60 seconds generally pass the EPA leak check criterion when checked with the entire sampling train. More significant leaks should be corrected. To prevent rupturing the impactor backup filter, the vacuum should be released at the sample nozzle.

It should be noted that the intent of this leak check procedure is not the elimination of every leak, but rather the detection of major problems such as missing o-rings. Small leaks are tolerated in this test because they do not significantly affect the quality of the impactor data. This is true for two reasons. First, the volume of the impactor is so small that a 60 second pressure drop of 5 to 6 inches Hg corresponds to a flow rate well within the EPA criterion of 0.02cfm. Furthermore, most impactors are not designed to be leak tight near the inlet of the device. This is due to the fact that during operation, the pressure drop to ambient at this point is essentially zero.

A negative gauge pressure leak check of the sampling train both with and without the collection device, should be performed as described in Section 5. When leak checking

the system with the impactor mounted on the probe, care should be taken to prevent rupturing the backup filter by backflow through the impactor.

An internal audit of the flow metering system is suggested as another method of detecting problems with the sampling train. To perform this system check, the metering orifice  $\Delta H$  is set to achieve a desired flow rate. It is recommended that the flow rate chosen be an actual calibration point for the 1.0 orifice. This recommendation is made on the basis that, occasionally, the curve fitted to orifice calibration data introduces significant error into the flow rate determination. Given the calibration flow rate for the orifice and the dry gas meter flow rate (obtained by measuring the length of the time for an arbitrary volume, such as 2.000 ft<sup>3</sup>, to pass through the meter) correct these two dry gas meter flow rates (calibration and audit) to standard conditions then determine their percent difference. An acceptance criterion of  $\pm 5$  percent is suggested but the needs of the sampling program may dictate adjustments to this value.

Problems such as impactor leaks, impactor stage overloading, bounce or reentrainment of particles can often be detected by examining the impactor substrates as they are unloaded. Note the appearance of each stage, substrate, or cyclone in a notebook or run sheet such as was shown in Section 4. A magnifying glass or low-power microscope will be useful when examining the deposits.

The shape of the deposits will provide some indication of whether or not bounce or reentrainment occurred during the run. An acceptable velocity through the jets usually results in a well-defined, cone-shaped pile of particulate matter while an excessive jet velocity yields a diffuse deposit. In extreme cases virtually none of the particles will be collected directly under the jets. Reentrainment is also more likely to occur at higher sampling flow rates. Streaks of particulate radiating out from the deposits may indicate that blow-off occurred and clumps of agglomerated material on the inlet surfaces of the jet plates almost certainly indicate that blow-off has occurred.

In addition to visual inspection, reentrainment due to stage overloading can be detected by running two otherwise identical tests for different sampling durations. If the size distribution measured in the longer run shows a pronounced bias toward smaller particles, overloading and reentrainment should be suspected. The operator must be aware, however, that substrate weight changes due to chemical reaction will not necessarily be the same for different sampling periods. Additional blank runs may be needed to resolve any doubts caused by possible substrate reactions.

If an internal leak in the impactor occurs, it can be found by careful inspection of the internal surfaces of the impactor as it is being unloaded. An unusual deposition pattern or an unusually dirty spot near a seal is a good indication. Also, an internal leak sometimes gives results similar to those obtained from reentrainment. Internal leaks are usually caused by improper impactor assembly. If an internal leak or improper assembly is suspected, reassemble the impactor before using it. Other internal leaks may be caused by nicked or warped metal or hardened rubber o-rings.

Although the choice of substrate surface should minimize substrate weight changes caused by reaction with the flue gas, blanks should still be run to quantify this effect. Blank substrates and backup filter can be included in each impactor run made if the construction of the impactor allows. The blank substrate should be added to the impactor set just before the backup filter with the collection plate turned upside down so that the substrate surface is out of flow. The blank filter should be placed directly behind the backup filter in the impactor, separated by Teflon or Kapton gaskets from the backup filter.

Entire impactor sets can also be run as blanks. Blank runs are made by attaching a prefilter to an impactor (no precollector is necessary) and operating the assembly in the same gas stream and under the same conditions of flow rate and sampling duration as a regular test run. The blank impactor is then unloaded and the substrates desiccated and weighed as usual. The changes in weight of the substrates in the blank run should then indicate the amount of the changes in weight (background) to be expected for the substrates in the regular test run. At least one blank run should be made each day when sampling sources where substrate weight changes may occur; in practice, this means virtually everywhere. If the blank run appears normal, the weight changes for all blank substrates of the same geometry are averaged and the average value is subtracted as a background correction from the weight gains observed for the regular test runs. Relatively large weight changes can be tolerated if they are uniform and reproducible from stage to stage and from one blank run to another.

Control runs are recommended as a means of quantifying any substrate weight changes caused by faulty standard handling procedures. Although such mechanical losses are not likely to be a factor with greased foils as with fiber mats, control runs are still suggested in either case. To perform a control run, an impactor is loaded as for a regular run. The inlet and outlet are plugged and the impactor is carried to the sampling site. The impactor is not operated, but is kept at the sampling site until the actual run is completed. Then the control is carried back to the laboratory and unloaded in the same way as the impactors for the regular runs. Every aspect of the treatment of the control is the same as that of a real run except that it is not operated in the stack. If the substrate loses or gains more than an average of 0.05 mg, additional care must be taken to improve the handling and/or weighing procedures.

Prior to performing the first impactor run, the isokinetic setup table should be checked to insure that the orifice and nozzle size chosen are acceptable. The recommended lower limit of orifice pressure drop,  $H$ , is 1.0 inch of water. Smaller values of  $H$  make it difficult to adjust to the correct flow rate. In cases where a particular cutpoint is desired from the sampler, such as 10  $\mu\text{m}$ , the proper flow rate can be critical. In most cases, the sample flow rate for an impactor will be much smaller than the flow rate used for Method 5 or Method 17 and the orifices used in the system for these methods will be too large to provide effective flow metering. In such a situation one of the smaller orifices should be used to obtain a larger  $H$  for the same impactor flow rate.

The sample flow rate required for the near isokinetic sampling with this nozzle should also be checked to insure it falls within the suggested operating limits or the impactor and does not contribute to the occurrence of bounce and reentrainment. Improper sample flow rates can be changed if a different nozzle size is used. If changes are made in either nozzle or orifice size, a new isokinetic setup table should be calculated.

A “wet” weighing of the undesiccated substrates from the first impactor run should be made to determine approximate stage loadings. Any adjustments in run time indicated should be made in subsequent runs.

At least one post-test dry weight of each substrate should be recorded on site. If possible, second weighings should also be performed in the field. Second weighings of every substrate may be avoided by performing second weighings on a random selection of 10 to 20 percent of the substrates. If the first weight in each case is reproduced to within 0.05mg, the first post-test weighing may be accepted as the final dry weight of all the substrates.

The final dry weight change of each substrate should be corrected for any blank weight changes. The magnitude of this correction is determined by averaging the weight changes for all blank substrates of the same geometry. This average value is subtracted as a background correction from substrate weight gains for each test run.

Field data sheets should be checked during and after each run to ensure that all needed information is (or has been) recorded. Pressure in the field to complete the sampling often leads to an attitude that one can fill in information at a later time from memory—this is a very poor practice and should be avoided.

### 7.3 SPECIAL SAMPLING CONDITIONS

The following paragraphs discuss various special sampling situations.

#### 7.3.1 HIGH PARTICULATE CONCENTRATIONS

Most impactors are designed for sampling at relatively low concentration outlets, downstream of particulate control equipment. Consequently many of these impactors are not suitable for sampling upstream of control equipment (inlet sampling situations) where the particulate concentrations may be as much as 10,000 times greater than at the outlet. Some impactors permit the operator to select from multiple stages, permitting the impactor to be configured for low flow rates.

#### 7.3.2 WET STACKS AND SUPPLEMENTAL HEATING

In sampling situations where the process stream contains entrained moisture or is near dew point, one must first define the measurement objectives: (1) Characterize only the particulate to be released to the atmosphere or (2) characterize both the particulate and entrained liquid/condensibles present in the flue. If the former is desired, as is normally

the case, one must provide supplemental heating to the impactor to prevent condensation from occurring in the impactor and to reevaporate entrained liquid droplets that would be evaporated in the downwind plume. Heat is usually supplied either by a heating pad properly sized for the impactor/precollector or by lengths of electrical heating tape. Glass fiber cord or tape may be used to secure the heating devices to the precollector, connecting tube, and impactor. Insulation should then be placed around the assembly and secured. A layer of aluminum foil wrap helps keep the insulation dry and aids in cleanup.

The temperature of the gas exiting the impactor should be monitored by a thermocouple exposed to the sample gas flow immediately upstream of the final filter, but the heating elements should be controlled by a second thermocouple between the impactor and the heater. A setting should be selected for this second thermocouple that will not damage the impactor but will raise the temperature of the exit gas about 20°F above the stack gas temperature (as monitored by the first thermocouple).

### 7.3.3 HIGH TEMPERATURE

Most source sampling is performed at sampling sites where the gas temperature is less than 350°F, as industrial processes generally use economizers which utilize heat from the exhaust stream to preheat incoming combustion air. Consequently, the temperature of the gas exiting the stack is generally maintained at temperatures of about 300°F. These low temperatures permit the use of coated metal substrates, Viton o-rings, and Teflon inserts. When it becomes necessary to sample at temperatures where the upper limits of these materials are exceeded one must use high temperature substitutes such as quartz substrates, metal o-rings, and Kapton inserts. Also, high temperature heater tapes would need to be used in the probe rather than the more durable moisture resistant silicone insulated heater tapes. Longer pre-run warmup times may also be required.

### 7.3.4 TOP ENTRY PORTS

In sampling situations where the duct is horizontal and the access ports are on the top of the duct, a special adapter must be used to attach the impactor to the probe. This adapter performs two major functions: (1) it rotates the impactor 180° so that it can be operated in an upright position rather than upside down and (2) it helps prevent the filter from being backwashed by water which might condense inside the probe and drain down to the end of the probe. Probe heaters are used and the adapter is wrapped with heater tapes and insulation. A thermocouple is used to monitor the probe exit temperature. Heater tapes on the adapter and probe are maintained at sufficiently high temperatures to assure that the gas exiting the probe is well above the dew point.

### 7.3.5 SMALL DUCTS

Special procedures and equipment must be used in small ducts when the cross-sectional blockage of the duct by the impactor/precollector assembly exceeds 5 percent

of the duct cross section area. In such situations one should attempt to rotate the impactor into the flow and use straight nozzles, provided cross-sectional blockage for this configuration does not exceed the 5 percent limit. A second option would be to connect a long pipe nipple to the port and install a longer connecting tube to the precollector so that only the precollector body is in the gas flow, the body of the impactor being located out of flow inside the long nipple. If such a configuration is used, one should construct a special removable curved flow shield around the connecting tube between the precollector and impactor body to prevent major flow interruptions being introduced by the port opening. This can be very significant when the port diameter is a substantial percentage of the duct diameter. The long pipe nipple will need to be heated and insulated and it may be necessary to use supplemental heating on the impactor body.

### 7.3.6 SIZE SEGREGATED SAMPLES FOR CHEMICAL ANALYSIS

If it is desired that size segregated samples be obtained for chemical analysis, special substrate material will be necessary. It is not possible to collect bulk quantities with cascade impactors but one can collect milligram quantities that may be analyzed by using trace element techniques such as x-ray analysis and Neutron Activation Analysis (NAA). Special substrates and filters must be used which give very low background signature for the elements desired. The polypropylene polymers substrate coatings, and quartz filters provide relatively clean signatures.

## 8 REFERENCE AND LIST OF CASCADE IMPACTORS

### Reference

“Recommended Methodology for the Determination of Particle Size Distributions in Ducted Sources,” Southern Research Institute, May 1986 (ARB Contract No. A3-092-32).

### LIST OF CASCADE IMPACTORS

Mark III Impactor  
Andersen Samplers Division of  
Andersen Group  
4215 Wendell Drive  
Atlanta, GA 30336

Model 1502 (MRI) Impactor TransTechnology  
Belfast Instrument Co.  
Subsidiary of TransTechnology Corp.  
727 South Wolfe Street  
Baltimore, MD 21231

Mark III and Mark IV Impactors



Flow Sensor Division of  
Andersen Group  
4215 Wendell Drive  
Atlanta, GA 30336

Mark III and Mark V Impactors  
Pollution Control Systems Corp.  
4530 Union Bay Place, N.E.  
Seattle, WA 98105

Model 226, 228, and 2210 Impactors  
Sierra Instruments Division of  
Andersen Group  
4215 Wendell Drive  
Atlanta, GA 30336

Brink Model C Impactor  
Zoltek Corporation  
3101 McKelvey Road  
St. Louis, MO 63044