1.0 PURPOSE

This procedure provides the methods for the collection, analysis, and reporting of soil samples in and around the Piñon Ridge Mill.

2.0 APPLICABILITY

This procedure applies only to annual routine soil sampling.

3.0 OTHER DOCUMENTS

3.1 *REFERENCES*

3.1.1 US Nuclear Regulatory Commission (NRC), Office of Standards Development, 1980. "Regulatory Guide 4.14, Radiological Effluent and Environmental Monitoring at Uranium Mills." Revision 1, April

3.1.2 ASTM Designation: C 998 – 90, Standard Practice for Sampling Surface Soil for Radioactivity, 2000

3.2 *EXHIBITS*

Exhibit 1 – Sample Submittal and Tracking Form EV-010A

4.0 EQUIPMENT AND MATERIALS

4.1 *EQUIPMENT*

4.1.1 10 cm x 10 cm x 5 cm stainless steel metal shovel.

4.1.2 5-cm diameter x 30-cm long stainless steel soil sampler.

4.1.3 Field Logbook.

4.1.4 Hand-held GPS unit.

4.2 *MATERIALS*

4.2.1 Sample Submittal and Tracking Form EV-010A or the equivalent.

4.2.2 23 cm x 33 cm (9" x 13") self-sealing sample bag or the equivalent

4.2.3 Wire brush or equivalent.

4.2.4 De-ionized water.

5.0 RESPONSIBILITY

5.1 The Radiation Safety Officer (RSO) or the Assistant RSO is responsible for:

5.1.1 Ensuring that the technicians obtaining soil samples are properly trained in soil sampling and sample chain of custody.

5.1.2 Assigning schedule of sampling events.

5.1.3 Ensuring Annual Report is filed with the Colorado Department of Public Health and Environment (CDPHE).

5.1.4 Ensuring that personnel considered as key individuals relevant to this procedure are documented as properly trained and/or qualified to perform

APPROVALS	*Signature*	*Date*
RSO		
Plant Manager		

the required duties.

5.1.5 Ensuring that the quality principles of this procedure are followed and maintained.

5.2 The Radiation/Security Technician (RST) is responsible for:

5.2.1 Having all necessary equipment and supplies prior to going to the field to obtain samples.

5.2.2 Advising the RSO or Assistant RSO of any deviations from planned activities or problems encountered during sampling events.

6.0 PREREQUISITE INFORMATION

6.1 *DEFINITIONS*

6.1.1 Sample Submittal and Tracking Form – Form used for initiating, tracking, and documenting all samples taken at the Piñon Ridge Mill.

6.2 *SAFETY*

6.2.1 Standard worker safety and handling of equipment should be observed when using this procedure.

6.3 *FREQUENCY*

6.3.1 Soil samples will be collected annually.

7.0 PROCEDURE

7.1 The RSO will determine the schedule for the annual soil sampling. The RST is to complete the Sample Submittal and Tracking Form EV-010A.

7.2 The RST acquires all necessary equipment and materials for the sampling effort.

7.3 The RST will take the soil samples at locations specified by the RSO. Samples should be taken as close to these exact locations as feasible. Designate the GPS coordinates on the Soil Submittal and Tracking Form EV-010A or attach a map upon which the sampling location is marked.

7.4 Latex gloves should be worn to protect the sampler from residual contamination on the hands and to protect the sample from cross-contamination.

7.5 Remove the top 5 cm of soil from a 10 cm x 10 cm area using the stainless steel shovel or take a 5 cm diameter plug 5 cm deep if using a soil sampler. Remove any large rocks or debris from the sample.

7.6 Place the soil in a self-sealing sample bag or equivalent.

7.7 Label the sample bag or equivalent using an indelible marker or prepared label with the location, date, and time the sample was taken and the Sample Submittal and Tracking Form EV-010A.

7.8 Fill out the necessary information on the Sample Submittal Tracking Form.

7.9 Note pertinent information in the field logbook form including the location, date and time of sample, description of sample location, site conditions, GPS coordinates, and any unusual circumstances encountered during the sampling effort.

7.9.1 Clean sampling equipment using a stiff bristle brush or other suitable

means to remove large particles, then rinse with de-ionized water, and dry the sampling equipment.

7.9.2 Continue sampling until all samples at all locations have been taken.

7.9.3 Take a second sample for quality assurance purposes just adjacent to the regular sample at 10% of the sampled locations.

7.10 The RST, on arriving back at the facility, will transfer sample custody to either the laboratory or the field custodian, and obtain their signature on the Sample Submittal and Tracking Form EV-010A.

7.11 Analyze the samples for U-nat, Pb-210, Th-230, Th-232, and Ra-226. The RSO will evaluate the analytical results and include that data along with any recommendations in the annual report to the Colorado Department of Public Health and Environment (CDPHE).

Soil Sampling Procedure EV-010

Exhibit 1

Sample Submittal and Tracking Form EV-010A

Sample Submittal and Tracking Form

COTTER CORPORATION SAMPLE SUBMITTAL AND TRACKING FORM

Sample Submittal Number C 17131

C:	P.O. Box 751 Canon City, CO 81215	S:	P.O. Box 1017 Golden, CO 80402	N:	P.O. Box 700 Nucla, CO 81424

Sample Loc./ID No. _____ Lab. No. _____

Sample Date _____ Date Recd. by D.R.C. _____

Sample Time _____ Date Recd. from QAC _____

Collected by _____ Date Data Entered _____

Field Custodian _____ Data Entry by _____

Delivered by _____ Laboratory Destination if not Cotter:

Received by _____ _____

Date Recd. _____ _____

Time Recd. _____ _____

1. Sample Type: Air _____ Water _____ Soil _____ Other (specify): _____
2. Analysis - Test series requested: _____
3. Field Data - Preservation: _____
4. Date analysis required by (if not Holding Time): _____
5. Special handling conditions or other instructions: _____
6. Sample procedures followed? If NO initial ( ) and explain below.
7. Sample security maintained? If NO initial ( ) and explain below.
8. Invalidating circumstances? If YES initial ( ) and explain below.

COMMENTS - Explanation of above items: _____

( ) Check if additional data or COMMENTS are attached.

QA Review:

Sample valid? YES ( ) NO ( ) If NO, explain: _____

QAC _____ Date _____

ANALYTICAL RESULTS ARE TO BE ATTACHED.

Forms\022.FRM (Rev. 3/15/93)

1.0 PURPOSE

This procedure specifies methods for performing quality control and quality assurance reviews (QA/QC) of analytical data for soil samples collected on and near the Piñon Ridge Mill site. It specifies the types of QA/QC samples that are collected and methods for analyzing the sample results.

2.0 APPLICABILITY

This procedure applies to all environmental soil sampling associated with the Piñon Ridge Mill.

3.0 OTHER DOCUMENTS

3.1 *REFERENCES*

3.1.1 U.S. Nuclear Regulatory Commission (NRC), Office of Standards Development, 1980. "Regulatory Guide 4.14, Radiological Effluent and Environmental Monitoring at Uranium Mills." Revision 1, April

3.1.2 NRC, Office of Nuclear Regulatory Research, 2007. "Regulatory Guide 4.15, Quality Assurance for Radiological Monitoring Programs (Inception through Normal Operations to License Termination) – Effluent Streams and the Environment." Revision 2, July

4.0 RESPONSIBILITY

4.1 The Radiation Safety Officer (RSO) or the Assistant RSO is responsible for:

4.1.1 Assigning QA/QC soil samples to be collected by the radiation/security technicians.

4.1.2 Reviewing data from quality control soil samples and taking corrective actions, if necessary.

4.2 The Radiation/Security Technician (RST) is responsible for:

4.2.1 Collecting QA/QC soil samples.

4.2.2 Filing of soil sample data and retaining the data.

5.0 PREREQUISITE INFORMATION

5.1 *FREQUENCY*

5.1.1 Duplicate soil samples are collected at a minimum rate of one for every 10 soil samples collected. A minimum of one duplicate soil sample will be collected per sampling event.

5.1.2 Equipment rinsate blanks and trip blank samples will be collected at the discretion of the RSO.

5.1.3 The laboratory will perform quality control under their own QA/QC program and may include analysis and evaluation of the following laboratory control samples:

APPROVALS	*Signature*	*Date*
RSO		
Plant Manager		

5.1.3.1 Method blanks

5.1.3.2 Laboratory fortified blanks

5.1.3.3 Laboratory control samples

5.1.3.4 Radiological tracers

5.1.3.5 Surrogates

5.1.3.6 Matrix spike samples

5.1.3.7 Matrix duplicates and matrix spike duplicates

5.1.3.8 Initial and continuing calibration verification samples

5.2 QUALITY ASSURANCE

Data collected under this procedure must meet the Project standards for precision, accuracy, representativeness, completeness, and comparability (PARCC), and must be scientifically valid, defensible, and of a defined quality. The objective of the sampling under this procedure is to provide concentrations of analytes of potential concern in soil. Quality Control (QC) will be achieved through the use of QC samples. The types of QC samples to be collected include field duplicates and blanks and laboratory duplicates, blanks, and spikes. The field QC samples are used to verify that sampling procedures, decontamination, packaging, and shipping are not introducing contaminants to the sampling event. The laboratory QC will be used to assess data quality in terms of precision and accuracy, and ensure analysis is being performed according to the methods. Laboratory QC is also included in each analytical method.

6.0 PROCEDURES

6.1 *DUPLICATE SAMPLES*

6.1.1 Sample Collection (see also procedure EV-010, Soil Sampling)

6.1.1.1 The RST will be responsible for collecting duplicate soil samples at assigned locations.

6.1.1.2 Soil samples will be collected in accordance with the soil sampling procedure with the following exceptions:

6.1.1.2.1 Collect excess soil

6.1.1.2.2 Homogenize the material by mixing in a self-sealing bag

6.1.1.2.3 Split into the primary and duplicate soil samples

6.1.1.3 Label the soil sample in such a manner that the primary soil sample ID is not included in the duplicate sample ID (e.g. DUP-01).

6.1.1.4 Record the duplicate ID on the sample sheet to allow for cross-reference of the lab data.

6.1.2 Data Review

6.1.2.1 Non-Radionuclide Data

6.1.2.1.1 Calculating the relative percent difference (RPD) for each primary/duplicate sample pair.

6.1.2.1.2 RPD is calculated as:

$$RPD = \frac{|S - D|}{(S + D) \times ½} \times 100$$

Where:
S = sample value
R = duplicate value

6.1.2.1.3 The RPD goal is less than 35 percent. If the data does not meet these criteria, refer to corrective actions in Section 6.5.

6.1.1.1 Radionuclide Data

6.1.1.1.1 Calculate the replicate error ratio (RER) for each primary/duplicate sample pair.

6.1.1.1.2 RER is calculated as:

$$RER = \frac{|S - D|}{\sqrt{(S \times 0.15)^2 + (E_S)^2 + (D \times 0.15)^2 (E_D)^2}}$$

Where:
S = sample value
E_S = sample counting error
D = duplicate value
E_D = duplicate counting error

6.1.1.1.3 The RER goal is less than 2. If the data does not meet these criteria, refer to corrective actions in Section 6.5.

6.2 *EQUIPMENT RINSATE SAMPLES*

6.2.1 Sample Collection

6.2.1.1 Equipment rinsate samples will be collected at the discretion of the RSO.

6.2.1.2 Equipment rinsate samples will be collected by pouring distilled water over freshly decontaminated sampling equipment into sample bottles.

6.2.1.3 Equipment rinsate samples will be analyzed for a subset or the full suite of constituents being analyzed for in the soil samples, at the discretion of the RSO.

6.2.1.4 Equipment rinsate samples are typically collected when sampling equipment is used for more than one sample location.

6.2.2 Data Review

6.2.2.1 The RSO will review the equipment rinsate data.

6.2.2.2 The levels of constituents in these samples should be non-detectable or minimal in relation to the corresponding constituent levels in the soil samples. If they are not, refer to corrective actions in Section 6.5.

6.3 ***TRIP BLANK SAMPLES***

6.3.1 Sample Collection

6.3.1.1 Trip blank samples are typically provided by the laboratory and simply need to be sent back with the collected samples. Do not open the trip blank sample bottles.

6.3.1.2 If the RSO would like to create a trip blank sample, then prepare a sample of distilled water. This should not be done in the field as contamination may be introduced.

6.3.1.3 Trip blank samples will be analyzed for a subset or the full suite of constituents being analyzed for in the soil samples, at the discretion of the RSO.

6.3.2 Data Review

6.3.2.1 The RSO will review the trip blank data.

6.3.2.2 The levels of constituents in these samples should be non-detectable or minimal in relation to the corresponding constituent levels in the soil samples. If they are not, refer to corrective actions in Section 6.5.

6.4 ***LABORATORY QA/QC DATA REVIEW***

6.4.1 Upon receipt of the sample receiving information from the laboratory, the following information will be reviewed for accuracy:

6.4.1.1 Analyses to be performed

6.4.1.2 Hold time

6.4.1.3 Sample receipt information

6.4.1.4 Chain-of-custody information

6.4.2 The laboratory QA/QC data provided with the laboratory report will be reviewed including:

6.4.2.1 Case narrative

6.4.2.2 Qualifiers identified on the results data sheets and extended qualifier report

6.4.2.3 Values on the quality control summary sheets

6.5 ***CORRECTIVE ACTIONS***

6.5.1 In the event that data falls outside of quality control limits, the RSO may take the following actions:

6.5.1.1 Review sample collection notes

6.5.1.2 Discuss with the sample collection personnel

6.5.1.3 Discuss with laboratory personnel

6.5.1.4 Discuss with the Vice President of Regulatory Affairs

6.5.1.5 Discuss with Colorado Department of Public Health and Environment (CDPHE) personnel

6.5.2 Based on the review of information above, the RSO may take on or more of the following corrective actions:

6.5.2.1 Accept the data as is

6.5.2.2 Qualify or reject the data

6.5.2.3 Collect a second sample from the same location (i.e. resample)

6.5.2.4 Instruct the laboratory to re-analyze the raw data

6.5.2.5 Instruct the laboratory to analyze remaining material from the sample

6.5.2.6 Calculate corrected soil sample data

6.5.2.7 Modify sample collection, handling, or analysis procedures

6.6 *REPORTING*

6.6.1 Any corrective actions taken will be reported to CDPHE in accordance with the conditions set forth in the current Colorado Radioactive Materials License.

1.0 PURPOSE

The purpose of the procedure is to describe methods of the collection, analysis, and reporting results of vegetation, forage, and crop samples in and around the Mill.

2.0 APPLICABILITY

This procedure applies to all vegetation, forage, and crop samples collected.

3.0 EQUIPMENT AND MATERIALS

3.1 *EQUIPMENT*

3.1.1 Pruning Shears.

3.1.2 Suitable container for sample storage.

3.2 *MATERIALS*

3.2.1 9 in. x 13 in. self-sealing bag.

3.2.2 Latex Gloves.

4.0 RESPONSIBILITY

4.1 The Radiation Safety Officer (RSO) is responsible for:

4.1.1 Determining the locations for the vegetation samples.

4.1.2 Determining the sampling dates and types of vegetation to be sampled based on the growing season.

4.1.3 Assigning the Radiation Security Technician (RST) to take the vegetation samples.

4.1.4 Ensuring that the sampling technician has sufficient experience and knowledge of the procedures to correctly obtain the samples.

4.2 The RST is responsible for:

4.2.1 Adhering to the following procedures.

5.0 PREREQUISITE INFORMATION

5.1 *SAFETY*

5.1.1 When sampling, precautions should be taken to avoid possible chemical hazards from crop treatment, i.e., pesticides, herbicides, and fertilizers. Avoid poisonous plants such as poison ivy.

5.2 *FREQUENCY*

5.2.1 Vegetation will be sampled during the growing season at the five air monitoring stations and/or other locations determined by the RSO, and three times during the grazing season at the Property boundary fence line along the east, west and south sides of the site. The fence-line sample locations will be determined by the highest predicted contaminant concentrations as determined by the most recent offsite dose assessment

APPROVALS	*Signature*	*Date*
RSO		
Plant Manager		

information.

6.0 PROCEDURE

6.1 The RST will collect the sample.

6.1.1 Sample collection of non-woody forbs, grasses, and/or shrubs will be severed using scissors or pruning shears no closer than 5 cm from the point where the plant emerges from the soil to avoid soil contamination.

6.1.2 A sample representative of the vegetation in the immediate vicinity will be collected at each air monitoring station.

6.1.3 A sample containing grass species only will be collected at the fence-line locations.

6.2 A sufficient volume of sample will be taken and placed in a self-sealing bag and labeled as to date, location and personnel collecting the sample.

6.3 The type of vegetation and relative percentage of each type of vegetation in the sample will be recorded.

6.4 Photographs will be taken of each sample site and of each sample.

6.5 The completed sample will be placed in a suitable container such as a plastic garbage bag.

6.6 The RST will ship the sample to the laboratory for analysis of radionuclides specified by the RSO.

6.7 The laboratory will report the data from the analysis to the RSO.

6.8 The RSO will review the analysis from the laboratory and make any necessary calculations needed for the annual report to the Colorado Department of Health and Environment.

1.0 PURPOSE

The purpose of this procedure is to describe the assessment of radiological content of wildlife on and near the Piñon Ridge Mill site.

2.0 APPLICABILITY

This procedure applies to all animal tissue sampling from rabbit and cattle specimens collected in the vicinity of the Mill.

3.0 OTHER DOCUMENTS

3.1 *REFERENCES*

3.1.1 "Baseline Survey of Radionuclides in Animal Tissues at the Proposed Piñon Ridge Mill Site," Department of Environmental and Radiological Health Sciences, CSU.

3.1.2 U.S. Nuclear Regulatory Commission (NRC), Office of Standards Development, 1980. "Regulatory Guide 4.14, Radiological Effluent and Environmental Monitoring at Uranium Mills." Revision 1, April

3.1.3 NRC, Office of Nuclear Regulatory Research, 2007. "Regulatory Guide 4.15, Quality Assurance for Radiological Monitoring Programs (Inception through Normal Operations to License Termination) – Effluent Streams and the Environment." Revision 2, July

3.2 *EXHIBITS*

Exhibit 1 – Specific Analyses for Specimen Tissue Samples

4.0 EQUIPMENT AND MATERIALS

4.1 *EQUIPMENT*

4.1.1 Dissection equipment

4.1.2 22-caliber rifle

4.2 *MATERIALS*

4.2.1 Clean plastic sheeting

4.2.2 Disposable gloves

4.2.3 Distilled water

4.2.4 Plastic sample bags

4.2.5 Ice

4.2.6 Non-phosphate soap (e.g. Alconox)

5.0 RESPONSIBILITY

5.1 The RSO or Assistant RSO shall be responsible for:

5.1.1 Training of employees for tissue collection.

APPROVALS	*Signature*	*Date*
RSO		
Plant Manager		

5.1.2 Assigning schedules to RST's for sample collection.

5.1.3 Review of analytical results and taking corrective action, if necessary.

5.1.4 Ensuring that necessary reports are filed with the Colorado Department of Public Health and Environment (CDPHE).

5.2 RST's shall be responsible for:

5.2.1 Collection of specimens.

5.2.2 Dissecting specimens and properly storing samples.

5.2.3 Keeping proper documentation of locations and number of samples collected in the field.

5.2.4 Shipping of tissue samples to analytical laboratory.

6.0 PREREQUISITE INFORMATION

6.1 *SAFETY*

6.1.1 Gun Safety – The use of a gun for this procedure requires strict adherence to NRA Gun Safety Rules.

6.1.2 Dissection tools are very sharp and should be handled with great care.

6.2 *FREQUENCY*

6.2.1 Representative tissue samples from rabbits are to be collected every 5 years, prior to renewal of the Mill Radioactive Materials License.

6.2.2 Tissue samples from cattle grazed within three kilometers of the mill site are to be collected if rabbit samples exhibit increasing levels of radiation.

7.0 PROCEDURE

7.1 *COTTONTAIL AND JACK RABBIT FIELD SAMPLE COLLECTION*

7.1.1 Obtain a scientific collection license for three each of cottontail rabbits and jack rabbits through the Colorado Division of Wildlife (CDOW).

7.1.2 Using a 20-caliber rifle, take three specimens of each rabbit species from representative on-site locations.

7.1.2.1 Cottontails are most abundant along southern boundary of the site in the piñon-juniper woodland areas.

7.1.2.2 Jack rabbits are most abundant toward the northern and central portions of the site in sagebrush and grass areas.

7.1.2.3 Greater success in taking the rabbits may be found in the early morning and late evening hours.

7.1.3 Record for each specimen:

7.1.3.1 Specimen number

7.1.3.2 Date

7.1.3.3 Location (be as specific as possible)

7.1.3.4 Species

7.1.3.5 Sex

7.1.3.6 Age

7.1.3.7 General condition of specimen

7.1.3.8 Method (rifle)

7.1.3.9 Name of collector

7.1.3.10 Any other information that might be relevant

7.1.4 Dissect each specimen in the field

7.1.4.1 Lay out clean, plastic sheeting.

7.1.4.2 Dissection tools should be decontaminated with distilled water and non-phosphate soap (e.g. Alconox) prior to and following dissection of each specimen.

7.1.4.3 Using dissection tools, separate into the following samples:

7.1.4.3.1 Bone Tissue – Remove and skin, hind legs, and shoulders of the animal (further dissection will be performed in the laboratory).

7.1.4.3.2 Liver Tissue – Remove the whole liver.

7.1.4.3.3 Lung Tissue – Remove the lungs from the chest.

7.1.4.4 Keep the tissue samples clean and free of dust, soil, etc.

7.1.4.5 Wash the external surface with distilled water, dry with paper towels, and place in sample bag.

7.1.4.6 Label the bag with a permanent marking pen (Species, animal number, date, type of tissue, and name of collector).

7.1.4.7 Place the bagged specimen in another sample bag, and label the second bag with the same information.

7.1.4.8 Place the sample on ice and into a cooler immediately to prevent tissue decay.

7.1.5 Store the samples in a freezer as soon as possible until they are ready for shipment to the analytical laboratory.

7.2 ***CATTLE SAMPLE COLLECTION***

7.2.1 Arrange with a local rancher and slaughterhouse to collect samples from three adult cows (3-4 years old) that have recently spent time grazing within three kilometers of the Mill site.

7.2.2 Record for each specimen:

7.2.2.1 Specimen number

7.2.2.2 Date

7.2.2.3 Location (be as specific as possible)

7.2.2.4 Species

7.2.2.5 Sex

7.2.2.6 Age

7.2.2.7 General condition of specimen

7.2.2.8 Method (slaughter)

7.2.2.9 Name of collector

7.2.2.10 Any other information that might be relevant

7.2.3 Obtain muscle, liver, lung and bone samples from the slaughterhouse.

7.2.3.1 Specifications for the samples follow:

7.2.3.1.1 Muscle Tissue – Obtain 2-3 pounds of fresh tissue from the area posterior to the femur in the hind leg. Select a cut, such as the round, with minimal fat content.

7.2.3.1.2 Liver Tissue – Take 2-3 pounds of the liver.

7.2.3.1.3 Lung Tissue – Take one-fourth of a lobe of the lung.

7.2.3.1.4 Bone Tissue – Take the scapula. Scrape the bone reasonably free of muscle tissue.

7.2.3.2 Keep the tissue samples clean and free of dust, soil, etc.

7.2.3.3 Wash the external surface with distilled water, dry with paper towels, and place in sample bag.

7.2.3.4 Label the bag with a permanent marking pen (Species, animal number, date, type of tissue, and name of collector).

7.2.3.5 Place the bagged specimen in another sample bag, and label the second bag with the same information.

7.2.3.6 Place the sample on ice and into a cooler immediately to prevent tissue decay.

7.2.4 Store the samples in a freezer as soon as possible until they are ready for shipment to the analytical laboratory.

7.3 ***SAMPLE STORAGE***

7.3.1 The samples are to be kept on ice in a cooler in the field and during transport.

7.3.2 The samples should be stored in a freezer at all other times.

7.4 ***SAMPLE SHIPMENT PROCEDURE***

7.2.1 Fill out the chain-of-custody with the contact information, sample identification, sample date/time, and requested analyses. Analyses to request specific to each species and tissue type are provided in Exhibit 1.

7.2.1.1 Analyses for uranium, Radium-226 and Lead-210 in rabbit bone will take precedent over all other tissue types.

7.2.1.2 Other species, tissue types and analytes to be analyzed will be conducted at the discretion of the RSO.

7.2.2 Verify that all samples are accounted for.

7.2.3 Double-bag ice in self-sealing bags.

7.2.4 Pack samples and ice into cooler. Note that extra ice should be included for warm weather periods.

7.2.5 Pack remainder of cooler with packing material. Shredded paper in Zip-loc bags is recommended.

7.2.6 Tape-up the cooler securely.

7.2.7 Affix the shipping label for overnight delivery.

7.2.8 Deliver sample coolers to shipment pick-up location.

7.5 ***ANALYTICAL REPORT REVIEW***

7.6.1 Specimen tissue analyses are reviewed and evaluated by the RSO.

7.6.2 The RSO will evaluate the specimen tissue analyses and report this data, conclusions, and any recommendations based on statistical and trend analysis to the Colorado Department of Public Health and Environment in accordance with the conditions set forth in the current Colorado Radioactive Materials License.

Animal Tissue Sampling Procedure EV-030

Exhibit 1

Specific Analyses for Specimen Tissue Samples

Specific Analyses for Specimen Tissue Samples

Sample	Tissue	Analyses Requested				
		U-nat	Th-230	Ra-226	Po-210	Pb-210
Cottontail/ Jack Rabbit	Muscle	X			X	
	Liver	X	X		X	X
	Lung				X	X
	Bone	X	X	X		X
Cattle	Muscle	X			X	
	Liver		X		X	X
	Lung				X	X
	Bone	X	X	X		X

Note: Analyses of specific species, tissue types, and for specific analytes will be conducted at the discretion of the RSO.

1.0 PURPOSE

This procedure specifies methods for environmental surface water sampling at stormwater samplers and springs on and near the Piñon Ridge Mill. It specifies methods for sampling, sample handling, documentation, analysis, and reporting associated with these surface water samples.

2.0 APPLICABILITY

This procedure applies to all environmental surface water sampling associated with stormwater samplers and springs on and near the Mill.

3.0 OTHER DOCUMENTS

3.1 *REFERENCES*

3.1.1 Colorado Rules and Regulations Pertaining to Radiation Control (6 CCR 1007-1), Part 4.

3.1.2 US Nuclear Regulatory Commission (NRC), Office of Standards Development, 1980. "Regulatory Guide 4.14, Radiological Effluent and Environmental Monitoring at Uranium Mills." Revision 1, April.

3.1.3 NRC, Office of Nuclear Regulatory Research, 2007. "Regulatory Guide 4.15, Quality Assurance for Radiological Monitoring Programs (Inception through Normal Operations to License Termination) – Effluent Streams and the Environment." Revision 2, July

3.1.4 Kleinfelder, 2008. "Work Plan for Surface Water Sampling." Revision 3, December 18

3.2 *EXHIBITS*

Exhibit 1 – Surface Water Sampling Sheet, Form EV-040A

4.0 EQUIPMENT AND MATERIALS

4.1 *EQUIPMENT*

4.1.1 Water Quality Meter and Calibration Standards

4.1.2 Pen

4.1.3 5-gallon bucket

4.1.4 Brush for decontamination

4.1.5 Sample transfer container (e.g. decontaminated 5-gallon bucket)

4.1.6 Peristaltic pump and associated tubing

4.1.7 Bailer (for surface water sampler method)

4.2 *MATERIALS*

4.2.1 Surface Water Sampling Sheet, Form EV-040A

4.2.2 Latex gloves

APPROVALS	*Signature*	*Date*
RSO		
Plant Manager		

4.2.3 Chain of Custody Form(s) (supplied by laboratory)

4.2.4 Sample bottles (supplied by laboratory)

4.2.5 Cooler(s) (supplied by laboratory)

4.2.6 0.45 µm filter(s) for dissolved constituents

4.2.7 Distilled water

4.2.8 Non-phosphate soap (e.g. Alconox)

4.2.9 Ice, one 6 to 10 pound bag or block per cooler

4.2.10 Hand tools

4.2.11 Self-sealing plastic bags (e.g. Zip-loc), 1-gallon size

4.2.12 Shipping label(s)

4.2.13 Cloth or paper towels

5.0 RESPONSIBILITY

5.1 The Radiation Safety Officer (RSO) or the Assistant RSO is responsible for:

5.1.1 Assigning schedules to technicians for the monitoring of and sample collection from stormwater samplers and springs.

5.1.2 Ensuring that the technician(s) assigned to collect samples are properly trained.

5.1.3 Reviewing data from the surface water samples, and taking any corrective actions if necessary.

5.1.4 Ensuring that necessary reports are filed with the Colorado Department of Public Health and Environment (CDPHE).

5.2 The Radiation Security Technician (RST) is responsible for:

5.2.1 Performing monitoring and sample collection.

5.2.2 Reporting any inconsistencies or problems encountered during field activities to the RSO or Assistant RSO.

5.2.3 Filing of all surface water sample data.

6.0 PREREQUISITE INFORMATION

6.1 *DEFINITIONS*

6.1.1 Stormwater Sampler – A sampling box set in the drainage area so that the top is at ground level. Consists of a polyethylene catchment box, nesting inside a Quazite concrete composite vault. Within the box system a series of 0.020-inch slotted, 4-inch diameter polyvinyl chloride (PVC) tubes are used for pre-filtration to reduce sediments in the water samples.

6.2 *SAFETY*

6.2.1 Sample bottles may contain corrosive preservation chemicals. Take care when handling.

6.3 *FREQUENCY*

6.3.1 Rain gauge and stormwater samplers are checked following precipitation events and periods of snowmelt.

6.3.2 Up to one sample for each type of event (rainfall or snowmelt) per location per calendar quarter.

6.3.3 Actual number of samples collected is dependent on number of events producing run-off at the surface water sampling locations.

7.0 PROCEDURES

7.1 *WATER QUALITY METER CALIBRATION PROCEDURE*

7.1.1 The water quality meter should be calibrated within 24 hours prior to each sampling event, at least once each day of the sampling event, and within 24-hours following each sampling event.

7.1.2 Calibrate the water quality meter in accordance with the manufacturer's instructions.

7.2 *STORMWATER SAMPLING PROCEDURE*

7.2.1 Following precipitation events, the rain gauges collocated with each stormwater sampler will be checked. Rain gauges are cleaned and emptied after each precipitation event.

7.2.2 Following precipitation or periods of snowmelt, the stormwater sampler will be checked for contents.

7.2.3 If surface water is present in the stormwater samplers, a sample is collected as soon as practical.

7.2.4 Don latex gloves.

7.2.5 Remove the lid of the sampler by removing bolts that secure the lid.

7.2.6 Record precipitation gauge reading (if applicable) and levels of water on the Surface Water Sampling Sheet.

7.2.7 Measure and record field water quality parameters (temperature [T], pH, specific conductance [SC], dissolved oxygen [DO], and oxidation reduction potential [ORP]).

7.2.8 Remove one or more of the caps from the PVC tubes.

7.2.9 Using a bailer, remove water from the tubes and transfer directly into sample bottles.

7.2.10 Typically, the surface water samples will be too heavily sediment-laden to filter. Follow these instructions for samples requiring filtration.

7.2.10.1 Remove any preservative in the bottle by triple rinsing with sample water.

7.2.10.2 Collect sample directly into bottle.

7.2.10.3 Indicate on the chain-of-custody (COC) that lab filtering is required.

7.2.11 Immediately cap sample bottles as they are filled, complete the required information on the bottle label, and place them in the cooler on ice.

7.2.12 When sampling is complete, remove the sampler liner and dump out remaining water downstream of the sampler.

7.2.13 Bail out the sampler vault with a bucket to as dry as practical.

7.2.14 Replace liner and PVC tube assembly with a previously decontaminated assembly.

7.2.15 Replace sampler lid.

7.2.16 Ensure that all necessary information has been recorded on the sample bottle labels and the Surface Water Sampling Sheet.

7.3 ***SAMPLE SHIPMENT PROCEDURE***

7.3.1 Fill out the chain-of-custody with the contact information, sample identification, sample date/time, and requested analyses.

7.3.2 Verify that all sample bottles are accounted for.

7.3.3 Double-bag ice in self-sealing bags.

7.3.4 Pack samples and ice into cooler (note that extra ice should be included for warm weather periods).

7.3.5 Pack remainder of cooler with packing material (shredded paper in zip-lock bags is recommended).

7.3.6 Tape-up the cooler securely.

7.3.7 Affix the shipping label for overnight delivery.

7.3.8 Deliver sample coolers to shipment pick-up location.

7.4 ***ANALYTICAL REPORT REVIEW***

7.4.1 Surface water analyses are reviewed and evaluated by the RSO.

7.4.2 The RSO will evaluate the surface water analyses and report this data, conclusions, and any recommendations based on statistical and trend analysis to the Colorado Department of Public Health and Environment in accordance with the conditions set forth in the current Colorado Radioactive Materials License.

Environmental Surface Water Sampling Procedure EV-040

Exhibit 1

Surface Water Sampling Sheet, Form EV-040A

ENERGY FUELS RESOURCES CORPORATION

Project: Piñon Ridge

SURFACE WATER SAMPLING FIELD DATA SHEET

Sampler No.	Sampling Equipment	Analytical Equipment	Sampler's Initials	Time	Date
	___ Disposable Bailer ___ Peristaltic Pump Other: (Describe Below)	**pH and Temp** ___ WTW 3400i Other: (Describe Below)			

Rainfall at site: (read on rain gauge on post)	
Water Level in Sample Box (in.)	
Amount of Water Removed For Sampling from sample Box (in.)	
Amount of Water Discarded in Drainage from sample Box (in.)	
Water Level In The Containment Box (in.)	
Amount of Water Discarded in the Drainage from containment Box (in.)	
Amount of Water Remaining in Containment Box (in.)	

Specific Conductivity
___ WTW 3400i
Other: (Describe Below)

Dissolved Oxygen
___ WTW 3400i
Other: (Describe Below)

Oxygen-Reduction Potential
___ WTW 3400i
Other: (Describe Below)

Meter Calibration

Time: Automatic Calibrations? Yes No

pH Cond. D.O. ORP

pH

pH std. # 1 = **4.01** at °C **Calibration Evaluation**

pH std. # 2 = **7.00** at °C Bars

Slope = mV/pH **Assymetry =** mV

Specific Conductance

Cell Constant = /cm **Calibration Evaluation** Bars

Dissolved Oxygen

RelativeSlope = at °C **Calibration Evaluation** Bars

Oxygen-Reduction Potential

Conductance Standard: **230** mV **Reads:** mV

Time (MST)	Temperature (°C)	pH (s.u.)	Specific Conductivity (µS/cm)	DO (mg/L)	ORP (mV)	Visual Description

Condition of Sampler:

Full Suite: Yes / No
#
Partial Suite: Yes / No
#

Duplicate Yes \ No #
Rinsate Yes \ No #
Trip Blank Yes \ No #

Additional Comments:

PPE Utilized
Gloves
Safety Glasses

Signature:

1.0 PURPOSE

This procedure specifies methods for performing quality control and quality assurance reviews (QA/QC) of analytical data for surface water samples collected on and near the Piñon Ridge Mill site. It specifies the types of QA/QC samples that are collected and methods for analyzing the sample results.

2.0 APPLICABILITY

This procedure applies to all environmental surface water sampling associated with the Piñon Ridge Mill.

3.0 OTHER DOCUMENTS

3.1 *REFERENCES*

3.1.1 U.S. Nuclear Regulatory Commission (NRC), Office of Standards Development, 1980. "Regulatory Guide 4.14, Radiological Effluent and Environmental Monitoring at Uranium Mills." Revision 1, April

3.1.2 NRC, Office of Nuclear Regulatory Research, 2007. "Regulatory Guide 4.15, Quality Assurance for Radiological Monitoring Programs (Inception through Normal Operations to License Termination) – Effluent Streams and the Environment." Revision 2, July

4.0 RESPONSIBILITY

4.1 The Radiation Safety Officer (RSO) or the Assistant RSO is responsible for:

4.1.1 Assigning QA/QC surface water samples to be collected by the radiation/security technicians.

4.1.2 Reviewing data from quality control surface water samples and ta**k**ing corrective actions, if necessary.

4.2 The Radiation/Security Technician (RST) is responsible for:

4.2.1 Collecting QA/QC surface water samples.

4.2.2 Filing of surface water sample data and retaining the data.

5.0 PREREQUISITE INFORMATION

5.1 *FREQUENCY*

5.1.1 Duplicate surface water samples are collected at a rate of one per sampling location per year.

5.1.2 Equipment rinsate blanks and trip blank samples will be collected at the discretion of the RSO.

5.1.3 The laboratory will perform quality control under their own QA/QC program and may include analysis and evaluation of the following laboratory control samples:

5.1.3.1 Method blanks

APPROVALS	*Signature*	*Date*
RSO		
Plant Manager		

5.1.3.2 Laboratory fortified blanks

5.1.3.3 Laboratory control samples

5.1.3.4 Radiological tracers

5.1.3.5 Surrogates

5.1.3.6 Matrix spike samples

5.1.3.7 Matrix duplicates and matrix spike duplicates

5.1.3.8 Initial and continuing calibration verification samples

5.2 QUALITY ASSURANCE

Data collected under this procedure must meet the Project standards for precision, accuracy, representativeness, completeness, and comparability (PARCC), and must be scientifically valid, defensible, and of a defined quality. The objective of the sampling under this procedure is to provide concentrations of analytes of potential concern in surface water. Quality Control (QC) will be achieved through the use of QC samples. The types of QC samples to be collected include field duplicates and blanks and laboratory duplicates, blanks, and spikes. The field QC samples are used to verify that sampling procedures, decontamination, packaging, and shipping are not introducing contaminants to the sampling event. The laboratory QC will be used to assess data quality in terms of precision and accuracy, and ensure analysis is being performed according to the methods. Laboratory QC is also included in each analytical method.

6.0 PROCEDURES

6.1 *DUPLICATE SAMPLES*

6.1.1 Sample Collection

6.1.1.1 The RST will be responsible for collecting duplicate surface water samples at assigned locations.

6.1.1.2 Surface water samples will be collected in accordance with the surface water sampling procedure with the following exceptions:

6.1.1.2.1 Duplicate analyses will be run for dissolved metals only.

6.1.1.2.2 Collect surface water in identical sample bottles to the primary sample for the constituents above.

6.1.1.2.3 Fill sample identical sample bottles from each set consecutively.

6.1.1.3 Label the surface water sample in such a manner that the primary surface water sample ID is not included in the duplicate sample ID (e.g. DUP-01).

6.1.1.4 Record the duplicate ID on the sample sheet to allow for cross-reference of the lab data.

6.1.2 Data Review

6.1.2.1 Non-Radionuclide Data

6.1.2.1.1 Calculating the relative percent difference (RPD) for each primary/duplicate sample pair.

6.1.2.1.2 RPD is calculated as:

$$RPD = \frac{|S - D|}{(S + D) \times ½} \times 100$$

Where:
S = sample value
R = duplicate value

6.1.2.1.3 The RPD goal is less than 50 percent. If the data does not meet these criteria, refer to corrective actions in Section 6.5.

6.1.2.2 Radionuclide Data

6.1.2.2.1 Calculate the replicate error ratio (RER) for each primary/duplicate sample pair.

6.1.2.2.2 RER is calculated as:

$$RER = \frac{|S - D|}{\sqrt{(S \times 0.15)^2 + (E_S)^2 + (D \times 0.15)^2 (E_D)^2}}$$

Where:
S = sample value
E_S = sample counting error
D = duplicate value
E_D = duplicate counting error

6.1.2.2.3 The RER goal is less than 2. If the data does not meet these criteria, refer to corrective actions in Section 6.5.

6.2 *EQUIPMENT RINSATE SAMPLES*

6.2.1 Sample Collection

6.2.1.1 Equipment rinsate samples will be collected at the discretion of the RSO.

6.2.1.2 Equipment rinsate samples will be collected by pouring distilled water over freshly decontaminated sampling equipment into sample bottles.

6.2.1.3 Equipment rinsate samples will be analyzed for a subset or the full suite of constituents being analyzed for in the surface water samples, at the discretion of the RSO.

6.2.1.4 Equipment rinsate samples are typically collected when sampling equipment is used for more than one sample location.

6.2.2 Data Review

6.2.2.1 The RSO will review the equipment rinsate data.

6.2.2.2 The levels of constituents in these samples should be non-detectable or minimal in relation to the corresponding constituent levels in the surface water samples. If they are not, refer to corrective actions in Section 6.5.

6.3 ***TRIP BLANK SAMPLES***

6.3.1 Sample Collection

6.3.1.1 Trip blank samples are typically provided by the laboratory and simply need to be sent back with the collected samples. Do not open the trip blank sample bottles.

6.3.1.2 If the RSO would like to create a trip blank sample, then prepare a sample of distilled water. This should not be done in the field as contamination may be introduced.

6.3.1.3 Trip blank samples will be analyzed for a subset or the full suite of constituents being analyzed for in the surface water samples, at the discretion of the RSO.

6.3.2 Data Review

6.3.2.1 The RSO will review the trip blank data.

6.3.2.2 The levels of constituents in these samples should be non-detectable or minimal in relation to the corresponding constituent levels in the surface water samples. If they are not, refer to corrective actions in Section 6.5.

6.4 ***LABORATORY QA/QC DATA REVIEW***

6.4.1 Upon receipt of the sample receiving information from the laboratory, the following information will be reviewed for accuracy:

6.4.1.1 Analyses to be performed.

6.4.1.2 Hold time.

6.4.1.3 Sample receipt information.

6.4.1.4 Chain-of-custody information.

6.4.2 The laboratory QA/QC data provided with the laboratory report will be reviewed including:

6.4.2.1 Case narrative.

6.4.2.2 Qualifiers identified on the results data sheets and extended qualifier report.

6.4.2.3 Values on the quality control summary sheets.

6.5 ***CORRECTIVE ACTIONS***

6.5.1 In the event that data falls outside of quality control limits, the RSO may take the following actions:

6.5.1.1 Review sample collection notes.

6.5.1.2 Discuss with the sample collection personnel.

6.5.1.3 Discuss with laboratory personnel.

6.5.1.4 Discuss with Colorado Department of Public Health and Environment (CDPHE) personnel.

6.5.2 Based on the review of information above, the RSO may take on or more of the following corrective actions:

6.5.2.1 Accept the data as is.

6.5.2.2 Qualify or reject the data.

6.5.2.3 Collect a second sample from the same location (i.e. resample).

6.5.2.4 Instruct the laboratory to re-analyze the raw data.

6.5.2.5 Instruct the laboratory to analyze remaining material from the sample.

6.5.2.6 Calculate corrected surface water sample data.

6.5.2.7 Modify sample collection, handling, or analysis procedures.

6.6 ***REPORTING***

6.6.1 Any corrective actions taken will be reported to CDPHE in accordance with the conditions set forth in the current Colorado Radioactive Materials License.

1.0 PURPOSE

This procedure specifies methods for environmental groundwater sampling of the monitoring, production, and domestic wells on and near the Piñon Ridge Mill site. It specifies methods for sampling, sample handling, documentation, analysis, and reporting associated with these groundwater samples.

2.0 APPLICABILITY

This procedure applies to all environmental groundwater sampling associated with monitoring, production, and domestic wells on and near the Mill site.

3.0 OTHER DOCUMENTS

3.1 *REFERENCES*

3.1.1 Colorado Rules and Regulations Pertaining to Radiation Control (6 CCR 1007-1), Part 4

3.1.2 US Nuclear Regulatory Commission, Office of Standards Development, 1980. "Regulatory Guide 4.14, Radiological Effluent and Environmental Monitoring at Uranium Mills." Revision 1, April

3.1.3 Kleinfelder, 2008. "Work Plan for Groundwater Sampling." Revision 2, May 21

3.1.4 Environmental Protection Agency Region I, 1996. "Low Stress (Low Flow) Purging and Sampling Procedure for the Collection of Ground Water Samples From Monitoring Wells." Revision 2, July 30

3.2 *EXHIBITS*

Exhibit 1 – Water Level Sheet, Form EV-050A

Exhibit 2 – Groundwater Sampling Sheet, Form EV-050B

4.0 EQUIPMENT AND MATERIALS

4.1 *EQUIPMENT*

4.1.1 Water Level Indicator

4.1.2 Water Quality Meter and Calibration Standards

4.1.3 Flow block

4.1.4 5-gallon bucket, two minimum

4.1.5 Well lock keys and/or combination

4.1.6 Pen

4.1.7 Brush for decontamination

4.1.8 For dedicated submersible pump method:

4.1.8.1 Adapter for pump pipe

4.1.8.2 Hose, 100 feet minimum

APPROVALS	*Signature*	*Date*
RSO		
Plant Manager		

4.1.8.3 Generator and extension cord, if required

4.1.9 For low-flow bladder pump method:

4.1.9.1 Bladder pump (if not present in well)

4.1.9.2 Pump tubing, dual 1/4" inside diameter (I.D.) polyethylene (PE), sufficient length to sample (if not present in well)

4.1.9.3 Sample tubing, dual 1/4" I.D. PE, approximately 5 feet per well with dedicated bladder pump

4.1.9.4 Bladder pump controller

4.1.9.5 12 volt or 120 volt power source for controller

4.1.9.6 Nitrogen cylinder (1 large cylinder per well)

4.1.9.7 Flow regulator

4.1.9.8 Teflon tape

4.1.10 For bailer method:

4.1.10.1 Bailer (if not present in well)

4.1.10.2 Rope, sufficient length to sample (if not present in well)

4.1.10.3 Sample transfer container (e.g. decontaminated 5-gallon bucket)

4.1.10.4 Equipment to retrieve bailer, if used (e.g. pulleys)

4.1.10.5 Peristaltic pump and associated tubing

4.1.11 For spring sampling:

4.1.11.1 Sample transfer container (e.g. decontaminated 5-gallon bucket)

4.1.11.2 Peristaltic pump and associated tubing

4.2 ***MATERIALS***

4.2.1 Water Level Sheet

4.2.2 Groundwater Sampling Sheet, Form EV-050A

4.2.3 Latex gloves

4.2.4 Chain of Custody Form(s) (supplied by laboratory)

4.2.5 Sample bottles (supplied by laboratory)

4.2.6 Cooler(s) (supplied by laboratory)

4.2.7 0.45 μm filter(s) for dissolved constituents

4.2.8 Distilled water

4.2.9 Non-phosphate soap (e.g. Alconox)

4.2.10 Ice, one 6 to 10 pound bag or block per cooler

4.2.11 Hand tools

4.2.12 Self-sealing plastic bags (e.g. zip-lock), 1-gallon size

4.2.13 Shipping label(s)

4.2.14 Cloth or paper towels

5.0 RESPONSIBILITY

5.1 The Radiation Safety Officer (RSO) or the Assistant RSO is responsible for:

5.1.1 Assigning schedules to technicians for the monitoring of and sample collection from groundwater wells and springs.

5.1.2 Ensuring that the technician(s) assigned to collect samples are properly trained.

5.1.3 Reviewing data from the groundwater samples, and taking any corrective actions if necessary.

5.1.4 Ensuring that necessary reports are filed with the Colorado Department of Public Health and Environment (CDPHE).

5.2 The Radiation Security Technician (RST) is responsible for:

5.2.1 Performing monitoring and sample collection.

5.2.2 Reporting any inconsistencies or problems encountered during field activities to the RSO or Assistant RSO.

5.2.3 Filing of all groundwater sample data and retaining the data.

6.0 PREREQUISITE INFORMATION

6.1 *DEFINITIONS*

6.1.1 Monitoring Well – A groundwater well installed for the purpose of collecting environmental groundwater samples. The well casing is typically constructed of 2” to 6” diameter PVC.

6.1.2 Production Well – A groundwater well installed for the purpose of collecting groundwater for use in milling and processing operations. The well casing is typically constructed of 6” to 12” diameter steel.

6.1.3 Domestic Well – A groundwater well installed for the purpose of collecting groundwater for domestic use. The well casing is typically constructed of 6” to 12” diameter steel.

6.1.4 Piezometer – A groundwater well installed for the purpose of taking groundwater level measurements. The well casing is typically 1” to 2” diameter PVC.

6.2 *SAFETY*

6.2.1 Sample bottles may contain corrosive preservation chemicals. Take care when handling.

6.2.2 Enclosed areas such as well boxes may contain biting or stinging insects. Care should be taken prior to entry.

6.2.3 Nitrogen cylinders contain high-pressure gas. Take appropriate precautions when handling.

6.3 *FREQUENCY*

6.3.1 Onsite Monitoring Wells

6.3.1.1 Monthly – Sampling during first year of operation.

6.3.1.2 Quarterly – Sampling from second year through end of operation.

6.3.2 Production Wells

6.3.2.1 Semimonthly – Water level measurements at piezometers near production wells during the aquifers transient state.

6.3.2.2 Monthly – Water level measurements at piezometers near production wells during the aquifers steady state.

6.3.2.3 Quarterly – Sampling during first year of operation.

6.3.2.4 Annually – Sampling from second year through end of operation.

6.3.3 Offsite Water Wells

6.3.3.1 Quarterly – Monitoring for productivity in pre-operational period.

6.3.3.2 Annually – Monitoring for productivity in operational period.

6.3.3.3 Annually – Sampling in pre-operational and operational periods.

6.3.3.4 Sampled any time that a water quality field parameter (other than temperature) changes by 20 percent or more between monitoring events.

6.3.4 Offsite Springs

6.3.4.1 Pre-Operational Period – Monitor for flow rate quarterly and sample semiannually.

6.3.4.2 Operational Period – Monitor for flow rate and sample semiannually.

7.0 PROCEDURES

7.1 *WATER LEVEL MONITORING PROCEDURE*

7.1.1 Conduct water level monitoring of all wells prior to sampling any of the wells.

7.1.2 Decontaminate water probe with a non-phosphate soap/distilled water solution and brush and rinse well with distilled water.

7.1.3 Turn on water level indicator to maximum sensitivity. If alarm sounds when not in water, turn down sensitivity until alarm stops.

7.1.4 Open well box, remove well casing cap and lower water level indicator into well. Do not let the water level indicator tape rub over side of well casing. A tape protector is included with the water level indicator and may be installed on the well casing. Slow down rate of descent when nearing expected water level.

7.1.5 When alarms sounds, pull up indicator probe until alarm stops and lower very slowly until alarm sounds again. Record the measurement from the tape to the nearest 0.01' at the top of the well casing on the north side of the well or where the casing is marked.

7.1.6 Record the water level on Water Level Sheet before retrieving indicator.

7.1.7 Retrieve water level indicator from the well, cleaning the tape as it is reeled up.

7.1.8 Decontaminate the water level indicator as described in 7.1.2 above.

7.1.9 Place cap on well and close and lock well box lid.

7.2 ***WATER QUALITY METER CALIBRATION PROCEDURE***

7.2.1 The water quality meter should be calibrated within 24 hours prior to each sampling event, at least once each day of the sampling event, and within 24-hours following each sampling event.

7.2.2 Calibrate the water quality meter in accordance with the manufacturer's instructions.

7.3 ***GROUNDWATER SAMPLING PROCEDURE – DEDICATED SUBMERSIBLE PUMP***

7.2.1 Take static water level measurements of all the wells to be measured in the area prior to sampling any of the wells.

7.2.2 Calculate and record the well casing volume of the saturated portion of the well by multiplying the saturated thickness in feet by the appropriate conversion factor for the diameter of the well casing. Conversion factors are given on the Groundwater Sampling Sheet.

7.2.3 Open the well box and remove the well casing cap.

7.2.4 Don latex gloves.

7.2.5 Install the adapter. The adapter should allow full flow through a main pipe with a sampling tee that converts to 1/4" or 3/8" I.D. sample tubing.

7.2.6 Install the hose on main flow pipe and run it away from well to the nearest surface drainage.

7.2.7 Install the flow block, water level quality meter, and probes at sample port of the adapter. Two water quality meters may be required so that all probes are plugged in and reading at the same time.

7.2.8 Turn on the well pump. It may take several minutes before water reaches the surface. Record the time that water reaches the surface.

7.2.9 Measure the flow rate by measuring the time required to fill a five-gallon bucket every five minutes.

7.2.10 Record flow rate, pH, temperature (T), Specific Conductance (SC), Dissolved Oxygen (DO), and Oxidation-Reduction Potential (ORP) in five-minute intervals. Ensure that correct units are indicated on the sheet.

7.2.11 Purge the well and continue recording readings and flow rates until stabilization occurs as indicated below.

7.2.11.1 For monitoring wells, purge until a minimum of three well casing volumes has been purged and the well readings (pH, T, SC, DO, and ORP) have stabilized. See stabilization parameters in 7.2.10.4 below.

7.2.11.2 For production wells, purge until the well readings have stabilized. See stabilization parameters in 7.2.10.4 below.

7.2.11.3 For offsite domestic wells, purge at full pump capacity or full well production capacity, whichever is less, for 20 minutes.

7.2.11.4 Stabilization is considered to be achieved when three consecutive readings, taken at three to five minute intervals, are within the following limits:

- pH: ± 0.1 unit
- Temperature: 3%
- Specific Conductance: 3%
- DO: 10%
- ORP: ± 10 millivolts

7.2.12 Disconnect the sampling tube upstream of the flow block for sampling.

7.2.13 Collect sample directly into sample bottles provided by the laboratory. Take care not to overfill bottles containing chemical preservatives.

7.2.14 Attach a 0.45 μm filter directly to sample tube to collect dissolved constituents as specified by the laboratory.

7.2.15 Immediately cap sample bottles as they are filled, complete the required information on the bottle label, and place them in the cooler on ice.

7.2.16 Collect a grab sample of filtered water and measure and record the filtered temperature and pH level of this sample.

7.2.17 Turn off sampling pump and disassemble the sampling equipment.

7.2.18 Clean the equipment with soap and water where necessary and place in appropriate containers.

7.2.19 Ensure that all necessary information has been recorded on the sample bottle labels and the Groundwater Sampling Sheet.

7.3 *GROUNDWATER SAMPLING PROCEDURE – LOW-FLOW BLADDER PUMP*

7.3.1 Take static water level measurement of all the wells to be measured in the area prior to sampling any of the wells.

7.3.2 Open well box and remove well casing cap.

7.3.3 Don latex gloves.

7.3.4 For a portable bladder pump:

7.3.4.1 Ensure the pump has been decontaminated prior to use.

7.3.4.2 Connect dedicated pump tubing to pump. Use of hose clamps is strongly recommended. The blue tube is air and should be connected to the edge fitting on the pump. The clear tube is for water and should be connected to the center fitting on the pump.

7.3.4.3 Lower pump into the well to the middle of screened interval of the well.

7.3.4.4 Secure tubing at the surface. The pump tubing is designed to support the weight of the pump.

7.3.5 For a dedicated bladder pump

7.3.5.1 Connect the sample tube to well cap connectors. The blue tube is air and should be connected to the edge fitting on the cap. The clear tube is for water and should be connected to the center fitting on the cap.

7.3.6 Install the water level indicator to the top of the water table. Refer to section 7.1.

7.3.7 Connect the air tube to the controller air output connector on the controller.

7.3.8 Connect the flow controller to the nitrogen cylinder and the air inlet fitting on the controller.

7.3.9 Connect the power cord to the controller. The controller can be operated on 12-volt DC or 120-volt AC power with supplied adapters.

7.3.10 Install flow block with water level quality meter and probes at the sample tube. Two water quality meters may be required so that all probes are plugged in and reading at the same time.

7.3.11 Open the nitrogen cylinder valve and flow controller valve to max open.

7.3.12 Adjust the pressure regulator to the required pressure. The required pressure can be calculated as the air tube length (depth of pump) x 0.5 plus 10 pounds per square inch (psi). For example, for a pump depth of 400 feet, the required psi is 400 x 0.5 + 10 = 210 psi.

7.3.13 Adjust charge and exhaust times. If previous charge and exhaust times were recorded for the well, use those. If not, follow these procedures:

7.3.13.1 Adjust charge and exhaust times to the maximum allowable setting.

7.3.13.2 When purging has started, adjust charge time down until the end of the charge cycle corresponds to the end of the purge from the sample tube. This adjustment saves compressed gas. Note that it may take two to three exhaust/charge cycles for the change in performance to be noticed.

7.3.13.3 Adjust the exhaust time down to coincide with the exhaust from the controller. This adjustment saves time.

7.3.14 Turn on the controller to start the purging of the well. Six to eight cycles may be required for water to reach the surface.

7.3.15 Record the water level, pH, temperature (T), Specific Conductance (SC), Dissolved Oxygen (DO), and Oxidation-Reduction Potential (ORP) in five-minute intervals. Ensure that correct units are indicated on the sheet.

7.3.16 Maintain the water level drawdown to as low as possible. Less than 0.1 foot of drawdown is ideal.

7.3.17 Purge the well and continue recording readings and water levels until the water quality parameters stabilize. Stabilization is considered to be achieved when three consecutive readings, taken at three to five minute intervals, are within the following limits:

- pH: ± 0.1 unit
- Temperature: 3%
- Specific Conductance: 3%
- DO: 10%
- ORP: ± 10 millivolts

7.3.18 Disconnect the sampling tube upstream of the flow block for sampling.

7.3.19 Collect sample directly into sample bottles provided by the laboratory. Take care not to overfill bottles containing chemical preservatives.

7.3.20 Attach a 0.45 μm filter directly to sample tube to collect dissolved constituents as specified by the laboratory.

7.3.21 Immediately cap sample bottles as they are filled, complete the required information on the bottle label, and place them in the cooler on ice.

7.3.22 Collect a grab sample of filtered water and measure and record the filtered temperature and pH level of this sample.

7.3.23 Turn off sampling pump and disassemble the sampling equipment.

7.3.24 Clean the equipment with soap and water where necessary and place in appropriate containers.

7.3.25 If using a portable bladder pump, decontaminate the pump with a non-phosphate soap and water solution and brush. Rinse with distilled water including pouring water through the pump (in the bottom of the pump and out the fitting on top of the pump).

7.3.26 Ensure that all necessary information has been recorded on the sample bottle labels and the Groundwater Sampling Sheet.

7.4 GROUNDWATER SAMPLING PROCEDURE – BAILER

7.4.1 Take static water level measurements of all the wells to be measured in the area prior to sampling any of the wells.

7.4.2 Calculate and record the well casing volume of the saturated portion of the well by multiplying the saturated thickness in feet by the appropriate conversion factor for the diameter of the well casing. Conversion factors are given on the Groundwater Sampling Sheet.

7.4.3 Open well box and remove well casing cap.

7.4.4 Don latex gloves.

7.4.5 Lower bailer into water table. Let bailer sink into water and retrieve bailer. Slow the rate of descent of the bailer as it approaches the water table to minimize disturbance of the water.

7.4.6 Repeat as necessary until three well casing volumes have been bailed or until the well is as dry as practical.

7.4.7 If the well was bailed dry, wait for the well to recharge sufficiently to obtain a full sample. This may take several days depending on the characteristics of the well.

7.4.8 Collect the samples directly into sample bottles provided by the laboratory. Take care not to overfill bottles containing chemical preservatives.

7.4.9 For the sample bottles requiring filtering, transfer sampled groundwater into a transfer container that has been properly decontaminated.

7.4.10 Attach a 0.45 µm filter to a peristaltic pump and pump the sample through the filter into the sample bottles, as specified by the laboratory.

7.4.11 Immediately cap sample bottles as they are filled, complete the required information on the bottle label, and place them in the cooler on ice.

7.4.12 Collect a grab sample of filtered water and measure and record the filtered temperature and pH level of this sample.

7.4.13 Clean the equipment with soap and water where necessary.

7.4.14 Ensure that all necessary information has been recorded on the sample bottle labels and the Groundwater Sampling Sheet.

7.5 ***SPRING SAMPLING PROCEDURE***

7.5.1 Open any valves or gates required to let the spring flow freely.

7.5.2 Measure the flow rate periodically by measuring the time required to fill a bucket of known volume.

7.5.3 When the flow had reached a steady state, the spring can be monitored.

7.5.4 Measure field water quality parameters on a grab sample and record the information on the sample sheet.

7.5.5 Fill sample bottles.

7.5.6 For samples requiring filtration:

7.5.6.1 Collect a sufficient volume for samples of spring water into a transfer container that has been properly decontaminated.

7.5.6.2 Attach a 0.45 µm filter to a peristaltic pump and pump the sample through the filter into the sample bottles, as specified by the laboratory.

7.5.7 Immediately cap sample bottles as they are filled, complete the required information on the bottle label, and place them in the cooler on ice.

7.5.8 Ensure that all necessary information has been recorded on the sample bottle labels and the sampling sheet.

7.6 ***SAMPLE SHIPMENT PROCEDURE***

7.6.1 Fill out the chain-of-custody with the contact information, sample identification, sample date/time, and requested analyses.

7.6.2 Verify that all sample bottles are accounted for.

7.6.3 Double-bag ice in self-sealing bags.

7.6.4 Pack samples and ice into cooler. Note that extra ice should be included for warm weather periods.

7.6.5 Pack remainder of cooler with packing material. Shredded paper in zip-lock bags is recommended.

7.6.6 Tape-up the cooler securely.

7.6.7 Affix the shipping label for overnight delivery.

7.6.8 Deliver sample coolers to shipment pick-up location.

7.6 ***ANALYTICAL REPORT REVIEW***

7.6.1 Groundwater analyses are reviewed and evaluated by the RSO.

7.6.2 The RSO will evaluate the groundwater analyses and report this data, conclusions, and any recommendations based on statistical and trend analysis to the Colorado Department of Public Health and Environment in accordance with the conditions set forth in the current Colorado Radioactive Materials License.

Environmental Groundwater Sampling Procedure EV-050

Exhibit 1

Water Level Sheet, Form EV-050A

ENERGY FUELS RESOURCES CORPORATION

WATER LEVEL MEASUREMENT FORM

Personnel: Zach Rogers

Project: Piñon Ridge Mill Site

Well ID	Date	Time	Casing Stick-up (ft ags)	Static Water Level (ft BTOC)	Total Depth (ft BTOC)	Casing Volume (gal)	Security		Comments
							Cap (Y/N)	Lock (Y/N)	

Casing Volume Multipliers (gal/ft): 1"=0.04 ; 2"=0.16 ; 3"=0.37 ; 4"=0.65

Environmental Groundwater Sampling Procedure EV-050

Exhibit 2

Groundwater Sampling Sheet, Form EV-050B

ENERGY FUELS RESOURCES CORPORATION

Project: Piñon Ridge Mill Site

GROUNDWATER SAMPLING FIELD DATA SHEET

Well No.	Purge Equipment	Analytical Equipment	Sampler's Initials	Time	Date
	____ Disposable Bailer ____ Bladder Pump ____ Grundfos Pump ____ Other:	**pH meter (temp):** ____ WTW 3400i ____ Other: Comments:			
Casing Diameter (in.)			**Meter Calibration**		
			Time: Automatic Calibrations? Yes No pH Cond. D.O. ORP		
Total Well Depth (ft.)	Comments:	**Cond. Meter (temp):** ____ WTW 3400i ____ Other: Comments:	**pH** **pH std. # 1 =** at °C **Calibration Evaluation** **pH std. # 2 =** at °C Bars **Slope =** mV/pH **Assymetry =** mV		
Static Water Level (ft.)	**Sample Equipment** ____ Disposable Bailer ____ Bladder Pump ____ Grundfos Pump ____ Other:		**Specific Conductance** **Cell Constant =** /cm **Calibration Evaluation** Bars		
Water Thickness (ft.)		**DO Meter:** ____ WTW 3400i ____ Other: Comments:	**Dissolved Oxygen** **RelativeSlope =** at °C **Calibration Evaluation** Bars		
Casing Volume (gal.)	Comments:				
	Filtration Equipment: ____ micron filter Comments:	**ORP Meter:** ____ WTW 3400i ____ Other: Comments:	**Oxygen-Reduction Potential** **Conductance Standard:** mV **Reads:** mV		
Stick-up (ft.) / **Screen Int.** (ft.)	**Water Level Meter:** ____ Keck ____ Other: Comments:	**Turbidity Meter:** ____ WTW ____ Other: Comments:			
Purge Containerized: ____ Yes ____ No **Destination:**			Casing Volume multipliers (gal/ft): 2"=(.16) 3"=(.37) 4"=(.65) 6"=(1.5)		

Time	Volume Removed (casings)	Volume Removed (gal)	Temp (°C)	pH (s.u.)	Cond (mS/cm)	DO (mg/L)	ORP (mV)	Water Level (ft below TOC)	Pumping Rate (gal/min)	Visual Description

Condition of Sampler:	**Full Suite: Yes / No**	**Pump Depth:**	**ft BTOC**
	#	**Duplicate** Yes \ No	#
	Partial Suite: Yes / No	**Rinsate** Yes \ No	#
	#	**Trip Blank** Yes \ No	#
Additional Comments:	**PPE Utilized**	Gloves Safety Glasses	
	Signature:		

1.0 PURPOSE

This procedure specifies methods for performing quality control and quality assurance reviews (QA/QC) of analytical data for groundwater samples collected on and near the Piñon Ridge Mill site. It specifies the types of QA/QC samples that are collected and methods for analyzing the sample results.

2.0 APPLICABILITY

This procedure applies to all environmental groundwater sampling associated with the Piñon Ridge Mill.

3.0 OTHER DOCUMENTS

3.1 *REFERENCES*

3.1.1 Colorado Rules and Regulations Pertaining to Radiation Control (6 CCR 1007-1), Part 4.

4.0 RESPONSIBILITY

4.1 The Radiation Safety Officer (RSO) or the Assistant RSO is responsible for:

4.1.1 Assigning QA/QC groundwater samples to be collected by the radiation/security technicians.

4.1.2 Reviewing data from quality control groundwater samples and taking corrective actions, if necessary.

4.2 The Radiation/Security Technician (RST) is responsible for:

4.2.1 Collecting QA/QC groundwater samples.

4.2.2 Filing of groundwater sample data and retaining the data.

5.0 PREREQUISITE INFORMATION

5.1 *FREQUENCY*

5.1.1 Duplicate groundwater samples are collected at a rate of one per sampling location per year.

5.1.2 Equipment rinsate blanks and trip blank samples will be collected at the discretion of the RSO.

5.1.3 The laboratory will perform quality control under their own QA/QC program and may include analysis and evaluation of the following laboratory control samples:

5.1.3.1 Method blanks

5.1.3.2 Laboratory fortified blanks

5.1.3.3 Laboratory control samples

5.1.3.4 Radiological tracers

5.1.3.5 Surrogates

APPROVALS	*Signature*	*Date*
RSO		
Plant Manager		

5.1.3.6 Matrix spike samples

5.1.3.7 Matrix duplicates and matrix spike duplicates

5.1.3.8 Initial and continuing calibration verification samples

5.2 QUALITY ASSURANCE

Data collected under this procedure must meet the Project standards for precision, accuracy, representativeness, completeness, and comparability (PARCC), and must be scientifically valid, defensible, and of a defined quality. The objective of the sampling under this procedure is to provide concentrations of analytes of potential concern in groundwater. Quality Control (QC) will be achieved through the use of QC samples. The types of QC samples to be collected include field duplicates and blanks and laboratory duplicates, blanks, and spikes. The field QC samples are used to verify that sampling procedures, decontamination, packaging, and shipping are not introducing contaminants to the sampling event. The laboratory QC will be used to assess data quality in terms of precision and accuracy, and ensure analysis is being performed according to the methods. Laboratory QC is also included in each analytical method.

6.0 PROCEDURES

6.1 *DUPLICATE SAMPLES*

6.1.1 Sample Collection

6.1.1.1 The RST will be responsible for collecting duplicate groundwater samples at assigned locations.

6.1.1.2 Groundwater samples will be collected in accordance with the groundwater sampling procedure with the following exceptions:

6.1.1.2.1 Duplicate analyses will be run for dissolved metals only.

6.1.1.2.2 Collect groundwater in identical sample bottles to the primary sample for the constituents above.

6.1.1.2.3 Fill sample identical sample bottles from each set consecutively.

6.1.1.3 Label the groundwater sample in such a manner that the primary groundwater sample ID is not included in the duplicate sample ID (e.g. DUP-01).

6.1.1.4 Record the duplicate ID on the sample sheet to allow for cross-reference of the lab data.

6.1.2 Data Review

6.1.2.1 Non-Radionuclide Data

6.1.2.1.1 Calculating the relative percent difference (RPD) for each primary/duplicate sample pair.

6.1.2.1.2 RPD is calculated as:

$$RPD = \frac{|S - D|}{(S + D) \times ½} \times 100$$

Where:
S = sample value
R = duplicate value

6.1.2.1.3 The RPD goal is less than 35 percent. If the data does not meet these criteria, refer to corrective actions in Section 6.5.

6.1.2.2 Radionuclide Data

6.1.2.2.1 Calculate the replicate error ratio (RER) for each primary/duplicate sample pair.

6.1.2.2.2 RER is calculated as:

$$RER = \frac{|S - D|}{\sqrt{(S \times 0.15)^2 + (E_S)^2 + (D \times 0.15)^2 (E_D)^2}}$$

Where:
S = sample value
E_S = sample counting error
D = duplicate value
E_D = duplicate counting error

6.1.2.2.3 The RER goal is less than 2. If the data does not meet these criteria, refer to corrective actions in Section 6.5.

6.2 *EQUIPMENT RINSATE SAMPLES*

6.2.1 Sample Collection

6.2.1.1 Equipment rinsate samples will be collected at the discretion of the RSO.

6.2.1.2 Equipment rinsate samples will be collected by pouring distilled water over freshly decontaminated sampling equipment into sample bottles.

6.2.1.3 Equipment rinsate samples will be analyzed for a subset or the full suite of constituents being analyzed for in the groundwater samples, at the discretion of the RSO.

6.2.1.4 Equipment rinsate samples are typically collected when sampling equipment is used for more than one sample location.

6.2.2 Data Review

6.2.2.1 The RSO will review the equipment rinsate data.

6.2.2.2 The levels of constituents in these samples should be non-detectable or minimal in relation to the corresponding constituent

levels in the groundwater samples. If they are not, refer to corrective actions in Section 6.5.

6.3 ***TRIP BLANK SAMPLES***

6.3.1 Sample Collection

6.3.1.1 Trip blank samples are typically provided by the laboratory and simply need to be sent back with the collected samples. Do not open the trip blank sample bottles.

6.3.1.2 If the RSO would like to create a trip blank sample, then prepare a sample of distilled water. This should not be done in the field as contamination may be introduced.

6.3.1.3 Trip blank samples will be analyzed for a subset or the full suite of constituents being analyzed for in the groundwater samples, at the discretion of the RSO.

6.3.2 Data Review

6.3.2.1 The RSO will review the trip blank data.

6.3.2.2 The levels of constituents in these samples should be non-detectable or minimal in relation to the corresponding constituent levels in the groundwater samples. If they are not, refer to corrective actions in Section 6.5.

6.4 ***LABORATORY QA/QC DATA REVIEW***

6.4.1 Upon receipt of the sample receiving information from the laboratory, the following information will be reviewed for accuracy:

6.4.1.1 Analyses to be performed

6.4.1.2 Hold time

6.4.1.3 Sample receipt information

6.4.1.4 Chain-of-custody information

6.4.2 The laboratory QA/QC data provided with the laboratory report will be reviewed including:

6.4.2.1 Case narrative

6.4.2.2 Qualifiers identified on the results data sheets and extended qualifier report

6.4.2.3 Values on the quality control summary sheets

6.5 ***CORRECTIVE ACTIONS***

6.5.1 In the event that data falls outside of quality control limits, the RSO may take the following actions:

6.5.1.1 Review sample collection notes.

6.5.1.2 Discuss with the sample collection personnel.

6.5.1.3 Discuss with laboratory personnel.

6.5.1.4 Discuss with Colorado Department of Public Health and Environment (CDPHE) personnel.

6.5.2 Based on the review of information above, the RSO may take on or more of the following corrective actions:

6.5.2.1 Accept the data as is.

6.5.2.2 Qualify or reject the data.

6.5.2.3 Collect a second sample from the same location (i.e. resample).

6.5.2.4 Instruct the laboratory to re-analyze the raw data.

6.5.2.5 Instruct the laboratory to analyze remaining material from the sample.

6.5.2.6 Calculate corrected groundwater sample data.

6.5.2.7 Modify sample collection, handling, or analysis procedures.

6.6 *REPORTING*

6.6.1 Any corrective actions taken will be reported to CDPHE in accordance with the conditions set forth in the current Colorado Radioactive Materials License.

1.0 PURPOSE

This procedure describes the meteorological monitoring program utilized at the Piñon Ridge Mill.

2.0 APPLICABILITY

This procedure applies to Mill personnel that operate, inspect, and summarize data for the meteorological monitoring stations.

3.0 OTHER DOCUMENTS

3.1 *REFERENCES*

3.1.1 USNRC Regulatory Guide 3.63, Onsite Meteorological Measurement Program for Uranium Recovery Facilities, 1988.

3.1.2 Work Plan for Ambient Air Monitoring, Kleinfelder, Revision 1, July 18, 2008.

4.0 EQUIPMENT AND MATERIALS

4.1 *EQUIPMENT*

4.1.1 The meteorological monitoring station is described in the Operational Monitoring Program.

4.2 *MATERIALS*

4.2.1 Site and/or instrument logbook.

5.0 RESPONSIBILITY

5.1 The Radiation Safety Officer (RSO) is responsible for:

5.1.1 Reviewing the meteorological data for accuracy, reformatting the data, and summarizing the data for inclusion in the annual report.

5.1.2 Scheduling the daily, monthly and quarterly checks of the weather station.

5.2 The Radiation Security Technician (RST) is responsible for:

5.2.1 Inspecting and cleaning the weather station.

5.2.1 Conducting the semiannual calibration checks.

6.0 PREREQUISITE INFORMATION

6.1 *SAFETY*

6.1.1 Mill Health and Safety Plan.

6.2 *FREQUENCY*

6.2.1 Weather monitoring is conducted continuously.

6.2.2 Checks of the equipment are conducted daily, weekly, and monthly.

6.2.3 Calibrations and audits of the meteorological equipment are conducted biannually.

APPROVALS	*Signature*	*Date*
RSO		
Plant Manager		

7.0 PROCEDURES

7.1 Refer to the "Work Plan for Ambient Air Monitoring" for procedures regarding operation, checks, calibrations and audits of the meteorological equipment.

1.0 PURPOSE

The purpose of this procedure is to conduct stack sampling at the Piñon Ridge Mill.

2.0 APPLICABILITY

This procedure is to measure emission rates and emitted concentrations of radionuclides from stack sources in support of determining the annual radionuclide release estimate.

3.0 OTHER DOCUMENTS

3.1 *REFERENCES*

3.1.1 40 CFR 60, Appendix A

3.1.2 Andersen Samplers, Inc., Equipment Manual

3.1.3 EPA-600, *Quality Assurance Handbook for Air Pollution Measurement Systems*, Volume III, Stationary Source Specific Methods

3.1.4 American National Standards Institute/Health Physics Society, Sampling and Monitoring Releases of Airborne Radioactive Substances from the Stacks and Ducts of Nuclear Facilities (ANSI/HPS N13.1-1999)

3.1.5 US NRC Regulatory Guide 4.14 Radiological Effluent and Environmental Monitoring at Uranium Mills

3.2 *EXHIBITS*

Exhibit 1 – Example of field data/calibration sheets

Exhibit 2 – Example showing the Isokenetic sampling calculations

Exhibit 3 – ANSI/HPS N13.1-1999

4.0 EQUIPMENT AND MATERIALS

4.1 *EQUIPMENT*

4.1.1 Anderson Universal Stack sampler system or the equivalent includes:

- Dry gas meter
- Sampling vacuum pump
- Dual manometers or Magnehelic gauges
- Temperature thermocouples
- Filter Hot box
- Glass impingers
- Ice bath cold box
- Sampling probe and assorted nozzles
- Sampling umbilical

4.1.2 Lab scale/balance

4.1.3 S-type (reverse) pitot tube

APPROVALS	*Signature*	*Date*
RSO		
Plant Manager		

4.1.4 Orsat analyzer

4.1.5 Barometer (or data may be obtained from local metrological station)

4.1.6 Electrical cords

4.1.7 Hand tools

4.2 ***MATERIALS***

4.2.1 Particulate filter for stack sampler (selected in conjunction with laboratory)

4.2.2 Suitable solvent reagent (selected in conjunction with laboratory)

4.2.3 Petri dish, rinse containers

4.2.4 Brushes

4.2.5 Ice/water

4.2.6 Silica gel (indicating type, 6-16 mesh size)

4.2.7 Teflon tape and/or silicone grease

4.2.8 Personal protective equipment

5.0 RESPONSIBILITY

5.1 The Radiation Safety Officer (RSO) or the Assistant RSO is responsible for:

5.1.1 Assigning schedules to the RST for the performance of stack samples at the required sampling locations.

5.1.2 Ensuring that the RST assigned to obtain, document, and conduct stack sampling are properly trained to perform the tasks.

5.1.3 Ensuring that the necessary reports are filed with the Colorado Department of Public Health and Environment (CDPHE).

5.2 The Radiation Security Technician (RST) is responsible for:

5.2.1 Collecting the samples according to the schedule and frequency provided by the RSO.

5.2.2 Ensuring that the equipment used for this sampling is properly calibrated and maintained.

5.2.3 Following the procedures contained herein to accomplish the sampling.

5.2.4 Reporting any inconsistencies or problems encountered to the RSO or Assistant RSO.

5.2.5 Filing the following documents:

- Stack sampling data sheets and calculation forms
- Sample Submittal Tracking Form
- Inputting the stack information from the field data sheets into the Laboratory Information Management System (LIMS)
- Preparing the stack sampling data summary report

5.2.6 Retaining forms for 3 years.

6.0 PREREQUISITE INFORMATION

6.1 *SAFETY*

6.1.1 Electrical hazards exist. Avoid wet or damp conditions to minimize the chance of electrical shock.

6.1.2 Use caution if working on elevated sampling platforms.

6.1.3 Glass items are used, watch for breakage.

6.1.4 Potentially hazardous materials are used and sampled, take precautions.

6.2 *FREQUENCY*

6.2.1 As specified by the RSO in order to obtain a representative annual radionuclide release estimate and in keeping with US NRC Regulatory Guide 4.14 (see Piñon Ridge Mill Operational Monitoring Plan).

7.0 TEST PROCEDURES

7.1 Sampling is accomplished following a hybrid program developed from EPA test Method 114 and Method 5 as referenced in 40 CFR Part 60, Appendix A. EPA Method 114 requires, by reference, the use of the American National Standards Institutes' (ANSI) Standard Procedure N13.1[(1)]. The ANSI standard also includes the methods specified in EPA Method 1, 2 and 2c. The ANSI standard was developed for light industrial/technical applications in the nuclear industry and is also designed to allow the user to perform a series of qualification evaluations and then to use single point sampling from that qualified location. This is useful when continuous or nearly continuous sampling is required. Since neither of the premises on which the ANSI standard was developed hold true for a heavy industry application such as a uranium mill, the procedure documented herein is a hybrid of the ANSI method and EPA Method 5 (which is the standard technique used for particulate sampling of industrial sources). To complete accurate sampling EPA Method 3 and 4 are also required. This procedure summarizes the referenced documents; however, to obtain reliable results, persons using this procedure must refer to 40 CFR Part 60, Appendix A, ANSI/HPS N13.1–1999, and the Andersen Samplers equipment and operating manual or the equivalent for specific and detailed information.

7.1.1 Method 114 is the controlling method that requires the use of Standard N13.1 to collect the sample. Method 114 is then used along with standard radiochemical laboratory procedures to analyze the sample collected.

7.1.2 Standard N13.1 presents how EPA Methods 1-4 are to be used, sets forth the performance metrics that must be met to qualify a stack sampling location, and provides the methodology for collecting a representative

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[1] Method 114 specifies ANSI N13.1–1969. In 1999, that procedure was substantively revised and renamed ANSI/HPS N13.1–1999. Although Method 114 has not been updated, the user is directed to utilize the 1999 procedure. This decision is in keeping with USEPA regulation 40 CFR Part 61 "National Emission Standards For Hazardous Air Pollutants Subpart I—National Emission Standards for Radionuclide Emissions From Federal Facilities Other Than Nuclear Regulatory Commission Licensees and Not Covered by Subpart H" which requires the use of the revised 1999 standard for new facilities. If subsequent to this writing, the ANSI standard is again revised, the user is instructed to evaluate the need for updating this procedure.

sample from the stack. This standard will be modified to also use EPA Method 5.

7.1.3 Method 1 is used to provide guidance for the selection of sampling ports and traverse points at which stack qualification will be performed. This method is designed to aid in the representative measurement of pollutant emissions and/or total volumetric flow rate from a stationary source. A measurement site where the effluent stream is flowing in a known direction is selected, and the cross-section of the stack is divided into a number of equal areas. Traverse points are then located within each of these equal areas.

7.1.4 Method 2 is used to determine the average velocity and the volumetric flow rate of a gas stream. The average gas velocity in a stack is determined from the gas density and from measurement of the average velocity head with a Type S (Stausscheibe or reverse type) pitot tube.

7.1.5 Method 3 is used to determine the dry molecular weight of a sample from the effluent gas stream. A gas sample is extracted from a stack by one of the following methods: (1) single-point, grab sampling; (2) single-point, integrated sampling; or (3) multi-point, integrated sampling. For dry molecular weight determination, an Orsat analyzer is used for the analysis. Method 3 is not specifically referenced in Standard N13.1 but is a sublevel reference from Method 2.

7.1.6 Method 4 is used to determine the moisture content of stack gas. A gas sample is extracted at a constant rate from the source; moisture is removed from the sample stream and determined either volumetrically or gravimetrically. Method 4 is not referenced in Standard N13.1 but is needed to allow results to be reported on a consistent basis as a concentration in dry air.

7.1.7 Method 5 is used to collect an integrated multipoint sample that is representative of the particulate matter concentrations across a stack that may or may not be well mixed. This standard is modified to also use qualification procedures from ANSI Standard N13.1-1999.

7.2 *METHOD 114*

7.2.1 Sample Collection

Samples will be collected using the procedures presented in Sections 7.3 through 7.6.

7.2.2 Radionuclide Analysis

7.2.2.1 Natural Uranium

Uranium may be measured chemically by either colorimetry or fluorometry. In both procedures, the sample is dissolved, the uranium is oxidized to the hexavalent form and extracted into a suitable solvent. Impurities are removed from the solvent layer. For colorimetry, dibenzoylmethane is added, and the uranium is

measured by the absorbance in a colorimeter. For fluorometry, a portion of the solution is fused with a sodium fluoride-lithium fluoride flux and the uranium is determined by the ultraviolet activated fluorescence of the fused disk in a fluorometer.

7.2.2.2 Thorium-230

Analysis for thorium-230 must be completed unless a relationship to natural uranium concentrations is known based on isotopic analysis of mill materials or other procedures. Analysis should occur using Method 114 Section 3.1 or 3.2 in which the thorium-230 is separated from the sample matrix using standard radiochemical techniques and is then deposited in a very thin film. The deposited element is then counted with an alpha spectrometer or alpha counter and the count is correlated to chemical mass using known reference standards.

7.2.2.3 Radium-226

Analysis for radium-226 must be completed unless a relationship to natural uranium concentrations is known based on isotopic analysis of mill materials or other procedures. Analysis should occur using Method 114 Section 3.1 or 3.2 in which the radium-226 is separated from the sample matrix using standard radiochemical techniques and is then deposited in a very thin film. The deposited element is then counted with an alpha spectrometer or alpha counter and the count is correlated to chemical mass using known reference standards.

7.2.2.4 Lead-210

Analysis for lead-210 must be completed unless a relationship to natural uranium concentrations is known based on isotopic analysis of mill materials or other procedures. Analysis should occur using Method 114 Section 3.3.1 or 3.3.3 in which the lead-210 is separated from the sample matrix using standard radiochemical techniques and is then either deposited in a very thin film or added to a scintillation cocktail. The element is then either counted with a beta counter or scintillation spectrometer and the count is correlated to chemical mass using known reference standards.

7.3 *STANDARD N13.1*

7.3.1 Sample Collection Point Qualification

7.3.1.1 Need for Pre-Qualification

In order to qualify as an acceptable sampling location, stack sample locations must meet the requirements of clause 5.2.2 of N13.1 (outlined below in Sections 7.2.2.4 and 7.2.2.5). Once these requirements are met, the location is considered “Qualified” and need not be reanalyzed unless flow conditions and or stack

geometry are significantly modified. Stack qualification parameters may influence the design of the stacks and it is suggested these parameters are evaluated prior to final design acceptance and again prior to commencement of initial operations.

7.3.1.2 Representative Stack Qualification

Often facilities have multiple stacks that are of similar design. For such situations, it is not necessary to completely test the sampling location in a candidate stack provided that:

7.3.1.2.1 A geometrically similar stack (one with proportional critical dimensions) has been tested and the sampling location has been found to comply with the requirements of clause 5.2.2. Critical dimensions are those associated with components of the effluent flow system that can influence the degree of contaminant mixing and/or the velocity profile. The prior testing may be conducted either on a stack in the field, or it may be conducted on a scale model.

7.3.1.2.2 The product of mean velocity (see equation A-2) times hydraulic diameter of the candidate stack or duct is within a factor of six of that of the tested stack or duct, and the hydraulic diameter of the stack or duct is at least 250 mm at the sampling location. The Reynolds numbers based on hydraulic diameter of both the candidate stack or duct and the tested stack or duct are greater than 10,000 (see equations B-1 and B-2 in N13.1 for examples of calculation of Reynolds numbers).

7.3.1.2.3 The velocity profile in the candidate stack or duct meets the requirements of Section 7.2.2.5 of this procedure.

7.3.1.2.4 The difference between velocity COVs of the two systems is not more than 5%.

7.3.1.2.5 The sampling location in the candidate stack or duct is placed at a geometrically similar location to that in the tested stack.

7.3.1.3 General Considerations

Locating a site in a stack or duct where a representative sample can be obtained by extractive methods involves finding a sampling location where; the contaminant profile is well mixed and stable, which is readily and safely accessible, which should not present a problem for sampling services and maintenance activities, and which should be able to accommodate sampling equipment. The sampling point should be downstream of all inputs and control

equipment. Bends, fans, and duct junctions may produce distortions in velocity and contaminant profiles and may introduce cyclonic flow that can adversely affect the representativeness of the sample; therefore, locations near such disturbances (upstream or downstream) should be avoided.

7.3.1.4 Cyclonic Flow

Measurements to determine if there is cyclonic flow are performed once and repeated only when velocity measurements indicate a substantial change. To determine if there is cyclonic flow, use Method 1 (Section 7.4 of this document). The criterion of acceptability is that the average flow angle shall not exceed 20 degrees (relative to the longitudinal axis of the stack or duct).

7.3.1.5 Velocity Profile

The stack cross section must be evaluated to determine if the velocity head profile is uniform across the stack or duct. The criterion for establishing the acceptable uniformity is that the coefficient of variation (COV), defined as the standard deviation as a percentage of the mean, of the stack gas velocity taken at the traverse points shall be less than or equal to 20% across an area that encompasses at least the center two-thirds of the cross-sectional area of the stack or duct. Measurement points (traverse point) at the candidate sampling location should be selected in accordance with Method 1. The traverse points for velocity (figure 1-2) in Method 1 shall be used for measurements. It may be necessary to add additional traverse points or to adjust the points in Method 1 for velocity mapping at the boundary demarcating 2/3 of the cross sectional area of the stack or duct or because of limitations of Method 1 regarding the proximity of a sampling point to a wall. The tests should be conducted while the stack flow rate is approximately the same as the expected normal flow rate.

7.3.2 Sample Collection

7.3.2.1 Volumetric Flow Measurement

Flow rate shall be measured in accordance with Method 1 and 2 as presented in Sections 7.4 and 7.5 of this procedure. In the summary of Methods 1 and 2 below, the following options from Annex A of Standard N13.1 have been selected:

- An S-type (reverse) pitot tube is used to limit clogging
- Stack mean molar mass is determined using Method 3 for stacks where water vapor may exceed 10% or other materials are present that may alter the mean molar mass by more than 4% from dry air.

7.3.2.2 Nozzle Design and Operation

- Sample nozzles must have a documented transmission ratio between 0.80 and 1.30 and an aspiration ratio within the range of 0.80 to 1.50. For determination of these values, the user is referred to Clause 6.3 of Standard N13.1.
- The total frontal area of the nozzle should not exceed 15% of the internal stack cross sectional area.

7.3.2.3 Particulate Sample Collection

7.3.2.3.1 Location

Sampling shall take place at a location qualified in accordance with Section 7.2.2 of this procedure.

7.3.2.3.2 Filter Media

Selection of filter media must be made by balancing three main factors: collection efficiency, filter material background radiation source, and ability to separate the sample from the filter in radiochemical procedures. Selection should be made in cooperation with the analytical laboratory. Filter collection efficiency must exceed 95% at the expected conditions of use. For additional guidance the user is referred to Clause 6.6.2 of Standard N13.1

7.3.2.3.3 Integrated Sample Collection

To ensure a representative sample is collected, the multi-point integrated isokinetic sampling technique presented in EPA Method 5 will be used.

7.3.2.4 Sample Volume Measurement

Sampling flowrate must be determined at the beginning and end of the sampling period if the sample flowrate will not vary by more than 20% over that period. The flowrate used in later calculations shall be the average of the two readings. If flowrate varies by more than 20% then measurements must be taken at least every ten minutes and the total sample volume value shall be the integrated value over time.

7.3.2.5 Sample Volume and Flow Rate

7.3.2.5.1 Select a combined sampling time and flow rate such that minimum total sample mass collected on the filter is sufficient to meet the laboratory analytical detection limit and data quality objectives.

7.3.2.5.2 The sampling time at each point shall be the same. The sampling time per point is not less than 2 minutes.

7.4 *METHOD 1*

7.4.1 Sampling Site Selection

7.4.1.1 Sampling and velocity measurements are performed at a

prequalified site or a site that is being prequalified. Ideally, the site is at least eight stack or duct diameters downstream and two diameters upstream from any flow disturbance such as a bend, expansion, or contraction in the stack, or from a visible flame.

7.4.2 Number and Location of Particulate Traverse Points

7.4.2.1 When the eight and two stack diameters upstream and downstream criterion can be met, the minimum number of traverse points is twelve, for stacks with diameters (or equivalent diameters) greater than 24 inches; eight for circular stacks with diameters between 12 and 24 inches.; and nine for rectangular stacks with equivalent diameters between 12 and 24 inches. For smaller stacks, refer to EPA Method 1 and 1a.

7.4.2.2 When the eight and two diameter criterion cannot be met, refer to the appropriate figure(s) shown in 40 CFR Part 60, Appendix A which specifies how to determine the minimum number of traverse points required.

7.4.2.3 Before referring to the figure(s), determine the distances from the measurement site to the nearest upstream and downstream disturbances, and divide each distance by the stack diameter or equivalent diameter, to determine the distance in terms of the number of duct diameters. Then, determine from figure(s) the minimum number of traverse points that corresponds to the number of duct diameters upstream and to the number of diameters downstream. Select the higher of the two minimum numbers of traverse points, or a greater value, so that for circular stacks the number is a multiple of four, and for rectangular stacks, the number is one of those shown in the figure.

7.4.2.4 Locate the traverse points on the two perpendicular diameters: for stacks having diameters greater than 24 in., no traverse points can be within 1.0 in. of the stack walls; for stack diameters equal to or less than 24 in., no traverse points scan be located within 0.50 in. of the stack walls.

7.4.2.5 When any of the traverse points fall within 1.0 in. or 0.50 in. of the stack walls, relocate them away from the stack walls to a distance of 1.0 in. or 0.50 in. or at a distance equal to the nozzle inside diameter, whichever is larger.

7.4.2.6 The relocated traverse points (on each end of a diameter) are identified as "adjusted" traverse points.

7.4.2.7 If two successive traverse points are combined to form a single adjusted traverse point, treat the adjusted point as two separate traverse points, both in the sampling and/or velocity measurement procedure, and in recording of the data.

7.4.2.8 For Rectangular Stacks, determine the number of traverse points

as noted above. From the figure(s) (40 CFR Part 60, Appendix A), determine the grid configuration. Divide the stack cross-section into as many equal rectangular elemental areas as traverse points, and then locate a traverse point at the centroid of each equal area.

7.4.2.8.1 The situation of traverse points being too close to the stack walls is not expected to arise with rectangular stacks.

7.4.3 Determination of Absence of Cyclonic Flow

To determine if there is cyclonic flow, use the following:

7.4.3.1 Level and zero a manometer and connect a Type S pitot tube to the manometer. Leak-check the system.

7.4.3.2 Position the Type S pitot tube at each traverse point, so that the planes of the face openings of the pitot tube are perpendicular to the stack cross-sectional plane; when the Type S pitot tube is in this position, it is at 0-reference point.

7.4.3.3 Note the differential pressure (Δp) reading at each traverse point. If a null (zero) pitot reading is obtained at 0-reference at a given traverse point, an acceptable flow condition exists at that point.

7.4.3.4 If the pitot reading is not zero at 0-reference, rotate the pitot tube, until a null reading is obtained.

7.4.3.5 Carefully determine and record the value of the rotation angle (α) to the nearest degree. After the null technique has been applied at each traverse point, calculate the average including any measurements where no rotation was required.

7.4.3.6 If the average value of is $\leq$ 20, the overall flow condition in the stack is acceptable for sample collection. If the average value is > 20 select a different location for sample collection.

7.5 ***METHOD 2***

7.5.1 Stack Velocity and Volumetric Flow Rate (Type S Pitot Tube)

7.5.1.1 Set up the apparatus as shown in the method. Capillary tubing or surge tanks installed between the manometer and pitot tube may be used to dampen Δp fluctuations.

7.5.1.2 Perform a pre-test leak check by blowing through the pitot impact opening until approximately 3.0 inches H_2O velocity head registers on the manometer; then, close off the impact opening. The pressure should remain stable for at least 15 seconds. Repeat the same for the static pressure side, except using suction to obtain the minimum of 3.0 inches H_2O.

7.5.1.3 Level and zero the manometer. Because the manometer level and zero may drift due to vibrations and temperature changes, make periodic checks during the traverse. Record all requested

information on the data sheets.

7.5.1.4 Measure the velocity head and temperature at the traverse points specified by Method 1.

7.5.1.5 When complete conduct a post-test leak check.

7.5.1.6 Measure the static pressure in the stack. One reading is adequate.

7.5.1.7 Determine the atmospheric pressure.

7.5.1.8 Determine the stack gas dry molecular weight.

7.5.1.8.1 For combustion processes or processes that emit essentially CO_2, O_2, CO, and N_2, use Method 3.

7.5.1.9 Obtain the moisture content from Method 4 or from Method 5.

7.5.1.10 Determine the cross-sectional area of the stack or duct at the sampling location. Do not assume that stack diameters are equal. Measure each diameter distance to verify its dimensions.

7.6 *METHOD 3*

7.6.1 Gas Analysis for Dry Molecular Weight Determination

A gas sample is extracted from a stack by one of the following methods, single-point grab sampling; single-point integrated sampling; or multi-point, integrated sampling. For the dry molecular weight determination, an Orsat analyzer is used for the analysis. The Orsat analyzer requires four reagents: a gas-confining solution, CO_2 absorbent, O_2 absorbent, and CO absorbent. Setup, maintain, and operate the Orsat gas analyzer according to the manufacturer specifications.

7.6.1.1 For samples obtained by grab sampling or single point integrated sampling, the collection point in the duct is at the centroid of the cross section.

7.6.1.2 For samples obtained using multi-point integrated sampling, collect the sample from all traverse sampling points. The sample is collected from a tap off the console dry gas meter.

7.6.1.3 Place the probe in the stack, with the tip of the probe positioned at the sampling point(s).

7.6.1.4 Purge the sampling lines, connect the collection bag, and make sure all connections are tight.

7.6.1.5 At the completion of sampling, close the valve on the sample bag.

7.6.1.6 Within 8 hours after the sample is taken, analyze it for percent CO_2 percent O_2 and percent CO using the Orsat gas analyzer.

7.7 *METHOD 4*

7.7.1 Moisture Content of Stack Gas Determination

This method is used for accurate determinations of moisture content. An approximation method is used to provide an estimate of percent moisture to aid in setting isokinetic sampling rates prior to a pollutant emission measurement run. When both moisture content and pollutant emission rate

are determined, the moisture determination is simultaneous with, and for the same total length of time as, the pollutant emission rate run.

7.7.1.1 Prepare and setup the sampling equipment.

7.7.1.2 Place known volumes of water in the first two impingers or transfer water into the first two impingers and record the weight of each impinger (plus water) to the nearest 0.5 grams (g). Weigh and record the weight of the silica gel to the nearest 0.5 g, and transfer the silica gel to the fourth impinger, or the silica gel may first be transferred to the impinger, and the weight of the silica gel plus impinger recorded.

7.7.1.3 Turn on the probe heater and the filter heating system to temperatures of approximately 248 ^{o}F to prevent water condensation ahead of the condenser. Allow time for the temperatures to stabilize.

7.7.1.4 Place crushed ice and water in the ice bath container.

7.7.1.5 Setup the metering system and sampling train.

7.7.1.6 When the sampling is used concurrently with Method 5, the sampling rate should be maintained at isokinetic conditions.

7.7.1.7 To begin sampling, position the probe tip at the first traverse point. Immediately start the pump, and adjust the flow to the desired rate. Traverse the cross section, sampling at each traverse point for an equal length of time. Add more ice and, if necessary, salt to maintain a temperature of less than 68 ^{o}F at the impinger silica gel outlet.

7.7.1.8 After collecting the sample, conduct a leak check of the sampling train. Record the leak rate. If the leakage rate exceeds the allowable rate, correct the sample volume as in Method 5.

7.7.1.9 Measure the volume of the moisture condensed in each of the impingers to the nearest milliliter (ml), or if the impingers were weighed prior to sampling, weigh the impingers after sampling and record the difference in weight to the nearest 0.5 g. Determine the increase in weight of the silica gel (or silica gel plus impinger) to the nearest 0.5 g. Record this information (see example data sheets) and calculate the moisture content.

7.7.1.10 Refer to the data sheets for calculations.

7.8 *METHOD 5*

7.8.1 Determination of Particulate Emissions from Stationary Sources

This method is performed in conjunction with Method 1 through Method 4. Before sampling can be conducted, select the sampling site and the minimum number of sampling points according to the guidelines and requirements listed in section 7.2 (Method 1), determine the stack pressure, temperature, and the range of velocity heads using the guidelines in section

7.3 (Method 2), determine the moisture content using the guidelines listed in section 7.5 (Method 4), and determine the stack gas dry molecular weight, using the guidelines described in section 7.4 (Method 3).

7.8.2 System Description

The stack sampling system contains five main components: probe, filter hot box, impinger cold box, umbilical, and control box console with sampling pump.

7.8.2.1 Probe Assembly

The probe assembly consists of a probe nozzle, probe sheath, heated probe liner, probe liner thermocouple, pitot tube and stack temperature thermocouple. The probe nozzle draws in a sample from the source effluent. The probe sheath protects the heated probe liner. Beneath the sheath, the probe liner is wrapped with heating wire that heats the probe. The liner can be maintained at a temperature of 248 ^{o}F +/- 25 ^{o}F to prevent condensation of the gas sample. The probe liner and stack temperature thermocouples sense the liner and stack temperatures. An S-Type pitot tube measures stack gas velocity by detecting a pressure difference that is proportional to stack gas velocity.

7.8.2.2 Filter Hot Box

An insulated, heated filter box contains the filter assembly to collect particulate from the gas sample while preventing condensation of moisture within the sample. If needed is also possible to put a cyclone separator before the filter holder to capture large particulate to minimize loading on the filter paper. The thermocouple in the filter box measures the temperature inside the heated box. The box temperature should be maintained at 248 ^{o}F +/- 25 ^{o}F to prevent condensation of the gas sample.

7.8.2.3 Impinger Cold Box

The impinger cold box contains three modified Greenburg-Smith bubblers and one standard Greenburg-Smith impinger, which are connected in series and surrounded by crushed ice. The ice lowers the sample gas temperature, which causes condensation inside the impinger. Moisture and other condensables are trapped for gravimetric or volumetric analysis. The sample gas temperature is measured upon exit and should be kept below 68 ^{o}F for complete moisture condensation.

7.8.2.4 Umbilical Cable

The umbilical cable contains the sample line, two pitot lines, type K thermocouples, power line, and a communication line.

7.8.2.5 Control Console

The control console box houses the dry gas meter, temperature controllers, temperature display, manometer, flow adjustment

valves, and pump, which create the flow for the sampling system.

7.8.2.5.1 The isokinetic sampling is maintained, by comparing the dry gas meter orifice pressure reading (ΔH) and the Pitot pressure reading (ΔP) and then by adjusting the ΔH accordingly. After exiting the impingers, the sample gas enters the controller through the umbilical sample line, passes through a filter to remove any foreign matter, which could damage the sampling pump or the dry gas meter and exits the system through a calibrated orifice. The calibrated orifice is connected to the manometer to allow a reference to the sample gas flow. The ΔP reading is then compared to the ΔH and flow is adjusted to maintain an isokinetic sampling rate. When required the Orsat sample is collected near the exit of the orifice tube. A maximum of 4 lpm should be collected to avoid interference with the ΔH reading.

7.8.3 Sampling Equipment Calibration

Calibration of the various sampling components before and/or after sample collection is required. Refer to 40 CFR Part 60, Appendix A, and the Andersen Samplers equipment and operating manual for the specific and detailed information.

7.8.3.1 Console Dry Gas Meter

A full calibration check of the console dry gas meter (DGM) is performed at least semiannually. The console DGM is compared to a Standard dry gas meter. The Standard dry gas meter is recertified once per year at an approved calibration facility.

7.8.3.1.1 Connect the console control unit to the Standard dry gas meter calibration device.

7.8.3.1.2 Run the control unit for a period of approximately 15 minutes to allow all components to warm up.

7.8.3.1.3 Adjust the flow rate to the desired flow. For a pre-test calibration, perform the checks over a range of flow set points. For the post- test calibration, the flow rate should be set to the average ΔH achieved during the sample runs.

7.8.3.1.4 Do not adjust the flow rate, turn the pump power off, and record the dry gas meter volume and calibration dry gas meter device volume.

7.8.3.1.5 Reset the timer.

7.8.3.1.6 Turn the pump and timer switches on simultaneously.

7.8.3.1.7 Record all data as requested on Meter Box Calibration Sheet. An example is included in Exhibit 1.

7.8.3.1.8 A minimum of 5 cubic feet are required at each flow rate.

7.8.3.1.9 Calculate the meter calibration factor (γ) and the orifice meter coefficient ($\Delta H_{@}$) for each flow setting.

7.8.3.1.10 The calibration is acceptable if all of the individual values are +/- 2% of the average. If the dry gas meter coefficient values obtained before and after a test series differ by more than 5%, recalibrate the meter over the full range of settings.

7.8.3.1.11 Any tests performed using a meter failing the 5% criteria may be voided or calculations performed using the γ (before or after) that gives the lower value of total sample volume will be used.

7.8.3.2 Pitot Tip S-Type Inspection

Before and after each field use, the pitot tube shall be carefully examined in top side and end views. If the pitot face openings are aligned within the specifications illustrated on the data sheet, it can be assumed that the baseline coefficient has not changed and no other calibration is required. If the inspection indicates that the measurements are greater than the tolerance limits, remove the pitot tube for repair and/or recalibration.

7.8.3.3 Thermocouple Checks

A full calibration of the system thermocouples is performed at least semiannually and in conjunction with the dry gas meter calibration.

7.8.3.3.1 For a full calibration, place the thermocouple into an ice bath and check against an NBS traceable mercury thermometer or a reference thermocouple and potentiometer. Record the temperatures of both the reference device and thermocouple on data sheet. Repeat these steps at higher temperatures using boiling water or another heat source. The measurements difference should be $\leq$ 1.5% for the stack sensor thermocouple and within 5.4 ^{o}F over the range for the other thermocouples.

7.8.3.3.2 For the post-test comparison, the thermocouples should agree within 10.8 ^{o}F of the reference thermometer at ambient temperature.

For a calibration check using a reference thermocouple kit, use the following:

7.8.3.3.3 Warm up the display for a period of approximately 10 minutes.

7.8.3.3.4 Attach a Standard Thermocouple Calibrator to the

input jacks and adjust the selector switch to that channel.

7.8.3.3.5 Set the calibrator to each temperature setting as requested on the data sheet and record the set point and display temperatures.

7.8.3.3.6 Complete the calibration before any adjustments to the display are made.

7.8.3.3.7 Using the calibration screws, adjust the high and low settings as needed.

7.8.3.3.8 Repeat the steps until the display and calibrator agree within +/- 5.4^{o}F.

7.8.3.3.9 Note that although the thermocouple is flexible, it is not designed to be bent sharply. Any sharp bend can cause damage to the inner insulation.

7.8.3.4 Nozzle Calibration Check

The following check on the nozzles is required before each use in the field.

7.8.3.4.1 Using a micrometer, measure the inside diameter of the nozzle to the nearest 0.001”. Make three separate measurements using different diameters each time, and obtain the average of the measurements. The difference between the high and low measurements shall not exceed 0.004”. Record the requested information on the data sheet.

7.8.3.4.2 If nozzles become nicked, dented or corroded they can be reshaped, sharpened, and recalibrated. The angle of the taper should be approximately 30°.

7.8.3.5 Differential Pressure Gauge Calibration Checks

If Magenhelic type gauges are used in place of manometers, the following checks are required.

7.8.3.5.1 For a full calibration check, compare the gauge measurement to a reference manometer measurement. Perform a minimum of three measurements over the flow range expected. Record all requested information on the data sheet. The difference between the gauge and manometer must be within 5%.

7.8.3.5.2 For the post-check, compare the gauge to the manometer at the average reading observed during the sampling test and record on the data sheet.

7.8.3.6 Analytical Balance/Scale Calibration

The analytical balance and scale used for weighing sampling filters and sampling reagents are calibrated annually by an

approved vender.

7.8.3.6.1 Prior to daily use, check the accuracy of the scale using a set of calibration weights.

7.8.3.6.2 Use a selection of three calibration weights over the range expected. Record all requested information on the data sheets. The scale readout should agree within +/- 1 g of the calibration weights.

7.8.3.7 Orsat Gas Analyzer

Setup and prepare the analyzer for use at the laboratory area. Refer to the Burrell operations manual for specific information.

7.8.3.7.1 Check and/or replace the gas absorbing reagents as needed.

- Di-Sorbent reagent is used for determining carbon dioxide.
- Cosorbent reagent is used for determining carbon monoxide.
- Oxorbent reagent is used for determining oxygen

7.8.4 Pre-Sampling Apparatus Checks

Periodic inspection of the sampling components is a must to ensure accurate sampling. Each of these items are generally checked before departing to the sampling site but may be completed at the sampling location.

7.8.4.1 Manometer

Visually inspect the orifice and pitot lines. They should be free of fluid. Any fluid found should be drained. The manometer can be cleaned with soap and water.

7.8.4.2 Impingers, Filter Holder and Glass Connectors

If residue is noticed, the glassware should be cleaned with a detergent solution and tap water and then rinsed with De-ionized distilled water. After drying, seal the glassware openings against possible contamination. Perform a visual inspection of the glassware. Look for cracks or breakage, repair or discarded if defective.

7.8.4.3 Probe Liner and Nozzle

Clean the probe and nozzle interior by brushing first with de-ionized distilled water and then rinsing with acetone; allow both to dry in a clean environment. The objective is to leave the nozzle and probe liner free of contaminants. After drying, the probe is sealed using foil or plastic wrap to minimize possible contamination. Check the probe heating system to see that it is operating properly. The heating element in the sampling probe is designed to keep the sample at 248 ^{o}F +/-25 ^{o}F. To separate the element from the liner remove the tape from each end and gently

pull off. To reinstall the element it may be useful to use talc or baby powder as a lubricant.

The sample probe exterior should be kept clean to eliminate contamination from one sample site to another. Inspect the clamps and welds to ensure that all are secure. Tighten or replace as necessary.

7.8.4.4 Pitot Tube Lines

To be certain the pitot lines are free of obstructions, gently blow through the pitot tube quick connects. The pitot tube gauge should respond. Be careful not to put more than ten inches of water pressure on the system.

7.8.4.5 Orifice Meter Lines

Check that the orifice lines are clean of obstructions. Turn off all switches except the Power and Pump switches. Carefully open the coarse and fine valves. The manometer should respond with movement. If no movement is observed check to be sure that all lines are connected and valves open. Also, move the Null switch to check to see that the solenoid valves are operating properly. You should hear a click when the Null switch is energized and the manometer will move to zero.

7.8.4.6 Temperature Controller

The dial type temperature controllers are set by turning the dial to the desired temperature setting. There are no user serviceable parts in this temperature controller.

7.8.4.7 Type K thermocouples

The thermocouples measure temperature. If a repair is necessary to any of the plugs, the red wire should be attached to the negative screw and the yellow to the positive screw. Note: A thermocouple that has its wires reversed will display a lower temperature as it is heated and vice-versa as it is cooled.

7.8.4.8 Quick Connects

A drop of penetrating oil helps keep the quick connects in good working order.

7.8.4.9 Control Console Leak Check

Before any calibration or sampling procedure, perform a system leak check. The meter system should be leak free. Either a positive (pressure) or negative (vacuum) leak checks can be performed. The positive pressure leaks check will check the metering system from the sample inlet quick connect to the orifice outlet including the inclined manometer.

7.8.4.9.1 Disconnect the orifice meter line from the downstream orifice pressure tap and plug this tap.

7.8.4.9.2 Vent the negative side of the manometer.

7.8.4.9.3 Place a one-hole rubber stopper with a tube through its hole into the exit of the orifice.

7.8.4.9.4 Connect the vacuum pump to the system.

7.8.4.9.5 Enable the positive side of the manometer.

7.8.4.9.6 Open the coarse and fine valves completely.

7.8.4.9.7 Blow into the tubing connected to the end of the orifice until a pressure of 5 to 7 inches H_2O has built up in the system.

7.8.4.9.8 Plug or crimp the tubing to maintain this pressure.

7.8.4.9.9 Observe the pressure reading for a period of one minute. No noticeable movement in the manometer reading should occur. If the system has a leak, a bubbling-type, soapy water, leak-check solution may aid in locating the leak(s).

7.8.4.9.10 The following is a negative pressure check that will check the vacuum system to-and-including the pump.

7.8.4.9.11 Plug the sample inlet to the meter box.

7.8.4.9.12 Turn the pump on and pull a vacuum of at least 20" Hg.

7.8.4.9.13 Observe the dry gas meter, if a leakage rate of 0.005 ft^3/min is indicated, the leak(s) must be found and minimized until the above specifications are satisfied.

7.8.4.10 Umbilical Cable

The umbilical cable should be inspected for damage to the outer covering. Any cuts, tears, or melted sections should be closely examined to ensure no damage to the electrical wires or sample lines.

7.8.4.11 Filter Preparation/Inspection

7.8.4.11.1 Check the filters visually against light for irregularities, flaws, and pinhole leaks.

7.8.4.11.2 Label the petri dishes and keep the filters in their respective dishes except during actual sampling and weighing.

7.8.5 Preparation of Sampling Train

The majority of the sampling train preparation is performed in the lab before departing to the sampling location. Once at the sampling location assemble all the system components.

7.8.5.1 During preparation and assembly of the sampling train, keep all openings where contamination can occur covered until just prior to assembly or until sampling is about to begin.

7.8.5.2 Set up and level the sampling console. Attach the lines from the umbilical cable. Connect the console unit to an electrical outlet.

7.8.5.3 Open the line vents and zero the manometer.

7.8.5.4 Set up the train, using the appropriate connecting glassware, if needed apply a light coat of silicone grease to the ball and the socket as well as the taper joint where the bottle and impinger stem meet and clamp each joint. A glass cyclone may be installed between the probe and filter holder when the total particulate catch is expected to exceed 100 mg or when water droplets are present in the stack gas.

7.8.5.5 Place 100 ml of water in each of the first two impingers, leave the third impinger empty, and transfer approximately 200 g of pre-weighed silica gel from its container to the fourth impinger. More silica gel may be used, but care should be taken to ensure that it is not entrained and carried out from the impinger during sampling.

7.8.5.6 Place the container in a clean place for later use in the sample recovery. Alternatively, the weight of the silica gel plus impinger may be determined to the nearest 0.5 g and recorded.

7.8.5.7 Using tweezers or clean disposable surgical gloves, place an identified filter in the filter holder. Be sure that the filter is properly centered and the gasket properly placed so as to prevent the sample gas stream from circumventing the filter. Be careful not to touch the filter surface as oils from your skin could absorb onto the filter and add to the final particulate catch. Each filter should be loaded such that the rough side will collect the particulate sample. Check the filter for tears after assembly is completed. Secure the filter holder into the filter hot box.

7.8.5.8 Attach the filter hot box onto the stack monorail, slide the impinger cold box on to the filter box and secure.

7.8.5.9 The stack monorail in marked to denote the proper distance into the stack or duct for each sampling point.

7.8.5.10 Attach the sampling probe with nozzle selected for sampling on to the filter hot box. Loosen the thumbscrew on the probe clamp and open completely. Insert the probe through the hole in the filter box until approximately 1.5” of the liner is visible from the inside of the filter box. Orient the pitot tubes so that the openings will face directly into the flow when inserted into the stack. Close the clamp and tighten the thumbscrew. Attach the appropriate sample, velocity, temperature, and power lines from the umbilical cable to the sampling probe, filter hotbox and impinger cold box.

7.8.5.11 Make sure to select a nozzle size based on the range of velocity heads, such that it is not necessary to change the nozzle size in order to maintain isokinetic sampling rates. During the run, do not

change the nozzle size.

7.8.5.12 Perform a visual inspection of the complete assembly checking to see that the thermocouple, pitot, and nozzle are aligned properly and all lines are secure.

7.8.5.13 Perform a leak-check the sampling system. After the sampling train has been assembled, plug the nozzle, start the pump, and pull a vacuum of 15 in. A lower vacuum may be used based on previous sampling results and experience, provided that it is not exceeded during the actual test.

7.8.5.14 Start the pump with the bypass valve fully open and the coarse adjust valve completely closed. Partially open the coarse adjust valve, and slowly close the bypass valve until the desired vacuum is reached. Do not reverse the direction of the bypass valve, as this will cause water to back up into the filter holder. If the desired vacuum is exceeded, either leak check at this higher vacuum, or end the leak check and start over.

7.8.5.15 When the leak check is completed, first slowly remove the plug from the inlet to the probe, filter holder, or cyclone (if applicable), and immediately turn off the vacuum pump. This prevents the water in the impingers from being forced backward into the filter holder and the silica gel from being entrained backward into the third impinger.

7.8.5.16 A leakage rate of $\leq$ 0.020 cubic feet per minute (cfm) is acceptable.

7.8.5.17 If, during the sampling run, a component (e.g., filter assembly or impinger) change becomes necessary, a leak check shall be conducted immediately before the change is made. The leak check shall be done according to the procedure outlined above, except that it shall be done at a vacuum equal to or greater than the maximum value recorded up to that point in the test. If the leakage rate is found to be no greater than 0.00057 cubic meter per minute (m^3/min) (0.020 cfm) or 4 percent of the average sampling rate (whichever is less), the results are acceptable, and no correction will need to be applied to the total volume of dry gas metered; if, however, a higher leakage rate is obtained, either record the leakage rate and plan to correct the sample volume or void the sample run. NOTE: Immediately after component changes, leak checks are optional. If such leak checks are done, the procedure outlined above should be used.

7.8.5.18 A post-test leak check of the sampling train is mandatory at the conclusion of sampling run. Perform the check in accordance with the procedures outlined above, except that it can be conducted at a vacuum equal to or greater than the maximum value reached during the sampling run. If the leakage rate is found to be no

greater than, 0.00057 m^3/min (0.020 cfm) or 4 percent of the average sampling rate (whichever is less), the results are acceptable, and no correction need be applied to the total volume of dry gas metered. If, however, a higher leakage rate is obtained, either record the leakage rate, and correct the sample volume or void the sampling run.

7.8.5.19 After the pre-test leak check has been conducted and is acceptable, place crushed ice and a small amount of water around the impingers. Turn on and adjust the filter, and probe heating systems to the desired operating temperatures.

7.8.5.20 Calculate the parameters needed for determining the isokinetic sampling rates. Examples of the calculations are included in Exhibit 2.

7.8.6 Sampling Train Operation.

7.8.6.1 During the sampling run, maintain an isokinetic sampling rate and a temperature around the filter of 248 +/- 25 ^{o}F.

7.8.6.2 For each run, record the data required on a data sheets such as the one shown in Figure. Be sure to record the initial DGM reading. Record the DGM readings at the beginning and end of each sampling time increment, when changes in flow rates are made, before and after each leak check, and when sampling is halted. Take other required readings at least once at each sample point during each time increment and additional readings when significant changes (20 percent variation in velocity head readings) necessitate additional adjustments in flow rate. Level and zero the manometer. Because the manometer level and zero may drift due to vibrations and temperature changes, make periodic checks during the traverse.

7.8.6.3 Clean the portholes prior to the test run to minimize the chance of collecting deposited material. To begin sampling, verify that the filter and probe heating systems are up to temperature, remove the nozzle cap, verify that the pitot tube and probe are properly positioned. Position the nozzle at the first traverse point with the tip pointing directly into the gas stream. Immediately start the pump, and adjust the flow to isokinetic conditions.

7.8.6.3.1 If the stack is under significant negative pressure, take care to close the coarse adjust valve before inserting the probe into the stack to prevent water from backing into the filter holder. If necessary, the pump may be turned on with the coarse adjust valve closed.

7.8.6.4 When the probe is in position, block off the openings around the probe and porthole to prevent unrepresentative dilution of the gas stream.

7.8.6.5 Traverse the stack cross-section, as determined by Method 1, being careful not to bump the probe nozzle into the stack walls when sampling near the walls or when removing or inserting the probe through the portholes; this minimizes the chance of extracting deposited material.

7.8.6.6 During the test run, make periodic adjustments to keep the temperature around the filter holder at the proper level; add more ice and, if necessary, salt to maintain a temperature of less than 68 ^{o}F at the condenser/silica gel outlet. Also, periodically check the level and zero of the manometer.

7.8.6.7 If the pressure drop across the filter becomes too high, making isokinetic sampling difficult to maintain, the filter may be replaced in the midst of the sample run. Before a new filter assembly is installed, conduct a system leak check. The total PM weight shall include the summation of the filter assembly catches.

7.8.6.8 At the end of the sample run, close the coarse adjust valve, remove the probe and nozzle from the stack, turn off the pump, record the final DGM meter reading, and conduct a post-test system leak check and also leak check the pitot lines as described in Method 2. The lines must pass this leak check, in order to validate the velocity head data.

7.8.7 Calculation of Percent Isokinetic

7.8.7.1 Calculate percent isokinetic (see calculations attachments) to determine whether the run was valid or if another test run should be made.

7.8.8 Sample Recovery.

7.8.8.1 The cleanup procedure begins as soon as the probe is removed from the stack at the end of the sampling period. Allow the probe to cool.

7.8.8.2 When the probe can be safely handled, wipe off all external particulate matter near the tip of the probe nozzle, and place a cap over it to prevent losing or gaining particulate matter. Do not cap off the probe tip tightly while the sampling train is cooling down. This could create a vacuum in the filter holder, thereby drawing water from the impingers into the filter holder.

7.8.8.3 Before moving the sample train to the cleanup site, remove the probe from the sample train, wipe off the silicone grease, and cover the open outlet of the probe. Be careful not to lose any condensate that might be present. Wipe off the silicone grease from the filter inlet where the probe was fastened, and cap or cover it. Remove the umbilical cord from the last impinger, and cap the impinger. After wiping off the silicone grease, cap off the filter holder outlet and impinger inlet. Stoppers, plastic caps, etc.

can be used to close these openings.

7.8.8.4 Disassemble all other equipment and materials and secure. Transfer the probe and filter-impinger assembly to the cleanup area. This area should be clean and protected from the wind so that the chances of contaminating or losing the sample will be minimized.

7.8.8.5 Inspect the train prior to and during disassembly, and note any abnormal conditions.

7.8.8.6 Carefully remove the filter from the filter holder, and place it in its identified petri dish container. Use a pair of tweezers and/or clean disposable surgical gloves to handle the filter. If it is necessary, use a dry Nylon bristle brush and/or a sharp-edged blade and carefully transfer to the petri dish any particulate matter and/or filter fibers that adhere to the filter holder gasket. Seal the container.

7.8.8.7 Taking care to see that dust on the outside of the probe or other exterior surfaces does not get into the sample, quantitatively recover particulate matter or any condensate from the probe nozzle, probe fitting, probe liner, and front half of the filter holder by washing these components with suitable solvent (selected based on the analytical procedures to be used) and placing the wash in a glass container. Perform the suitable solvent rinse as follows:

7.8.8.8 Carefully remove the probe nozzle. Clean the inside surface by rinsing with solvent from a wash bottle and brushing with a Nylon bristle brush. Brush until the solvent rinse shows no visible particles, after which make a final rinse of the inside surface with acetone.

7.8.8.9 Brush and rinse the inside parts of the fitting with solvent in a similar way until no visible particles remain.

7.8.8.10 Rinse the probe liner with suitable solvent by tilting and rotating the probe while squirting solvent into its upper end so that all inside surfaces will be wetted. Let the solvent drain from the lower end into the sample container. A funnel (glass or polyethylene) may be used to aid in transferring liquid washes to the container. Follow the solvent rinse with a probe brush. Hold the probe in an inclined position, squirt solvent into the upper end as the probe brush is being pushed with a twisting action through the probe; hold a sample container underneath the lower end of the probe, and catch any solvent and particulate matter that is brushed from the probe. Run the brush through the probe three times or more until no visible particulate matter is carried out with the solvent or until none remains in the probe liner on visual inspection. Rinse the brush with solvent, and quantitatively

collect these washings in the sample container. After the brushing, make a final solvent rinse of the probe. Seal and label the container.

7.8.8.11 At the lab area, mark the level of liquid on the container so that it can be confirmed whether leakage occurred during transport. If a noticeable amount of leakage has occurred, void the sample or contact the RSO for instructions to correct the final results. Transfer the rinsate along with the filters to the analytical laboratory for processing and analysis.

7.8.8.12 Between sampling runs, keep brushes clean and protected from contamination.

7.8.8.13 Save a portion of the solvent used for cleanup as a blank. Take this solvent directly from the wash bottle being used, and place it in a sample container. Label as solvent rinse blank. Submit to the analytical laboratory for processing and analysis.

7.8.8.14 Note the color of the indicating silica gel to determine whether it has been completely spent, and make a notation of its condition. Transfer the silica gel from the fourth impinger to its original container and seal. A funnel may make it easier to pour the silica gel without spilling. Weigh the spent silica gel (or silica gel plus impinger) to the nearest 0.5 g using a balance. Since the gain in weight is to be used for moisture calculations, do not use any water or other liquids to transfer the silica gel.

7.8.8.15 Make a notation of any color or film in the liquid catch. Measure the liquid that is in the first three impingers to within 1 ml by using a graduated cylinder or by weighing it to within 0.5 g by using a balance. Record the volume or weight of liquid present. This information is required to calculate the moisture content of the effluent gas. Discard the liquid after measuring and recording the volume or weight, unless analysis of the impinger catch is requested.

7.8.9 Run Calculations and Record Data

This section lists the equations necessary to perform isokinetic sampling. It is necessary to determine the stack pressure, temperature, molecular weight, approximate moisture content, and the range of velocity heads (Δp) that will be encountered during sampling. The data sheets list the required parameters and calculations. Carry out calculations, retaining at least one extra significant figure beyond that of the acquired data. Round off figures after the final calculation. Other equivalent forms of the equations may be used.

Examples of calculations used for isokinetic sampling are included in Exhibit 2.

Stack Sampling Procedure EV-070

Exhibit 1

Example of Field Data/Calibration Sheets

Example of Field Data/Calibration Sheets

SOURCE SAMPLING TITLE PAGE

Source Information				
Plant Name				
Sampling Location				
Fuel or Source Type				
Fuel F-Factor				

Test Information			
Starting Test Date			
Project #			
Operator			
Standard Temperature			°C
Standard Pressure			mm Hg
Minimum required sample vol.			scm
Run Duration			Minutes
Base Run Number			
# of Ports Available			
# of Ports Used			
Port Inside Diameter			mm
Circular Stack?		☐	
Rectangular Stack?		☐	

Test Equipment Information			
Meter Box Number			
Meter Calibration Factor	(Y)		
Orifice Meter Coefficient	($\Delta H_@$)		in H_2O
Pitot Identification			
Pitot Tube Coefficient	(C_p)		
Orsat Identification			
Nozzle Number			
Nozzle Diameter	(D_n)		mm
Probe Number			
Probe Length			m
(SS, Glass ....) Liner Material			
Sample Case / Oven Number			
Impinger Case Number			
Acetone Lot Number			

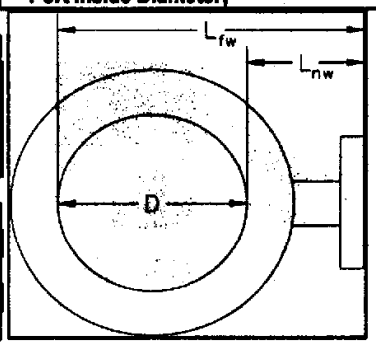
Testing Company Information	
Company Name	
Address	
City, State Country Zip	
Project Manager	
Phone Number	
Fax Number	

APEX INSTRUMENTS SOURCE TESTING EQUIPMENT

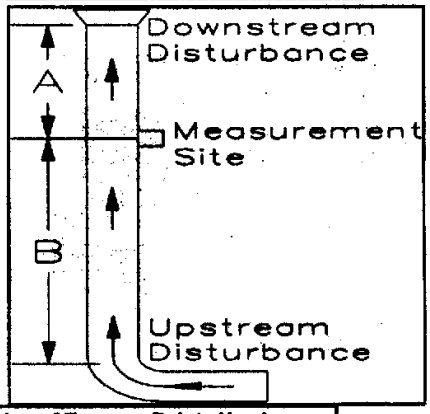
METHOD 1 - SAMPLE AND VELOCITY TRAVERSES FOR CIRCULAR SOURCES

Plant Name		Date	
Sampling Location		Project #	
Operator		# of Ports Available	
Stack Type		# of Ports Used	
Stack Size		Port Inside Diameter	

Circular Stack or Duct Diameter			
Distance to Far Wall of Stack	(L_{fw})		m
Distance to Near Wall of Stack	(L_{nw})		m
(=Lfw - Lnw) Diameter of Stack	(D)		m
(=3.14(D/2/Cunits)2) Area of Stack	(A_s)		m^2



Distance from Port to Disturbances			
Distance Upstream	(B)		m
(=B/D) Diameters Upstream	(B_D)		diameters
Distance Downstream	(A)		m
(=A/D) Diameters Downstream	(A_D)		diameters



Number of Traverse Points Required			
Diameters to Flow Disturbance		Minimum Number of[1] Traverse Points	
Up Stream	Down Stream	Particulate Points	Velocity Points
2.00-4.99	0.50-1.24	24	16
5.00-5.99	1.25-1.49	20	16
6.00-6.99	1.50-1.74	16	12
7.00-7.99	1.75-1.99	12	12
>= 8.00	>=2.00	8 or 12[2]	8 or 12[2]
Upstream Spec			
Downstream Spec			
Traverse Pts Required			

[1] Check Minimum Number of Points for the Upstream and Downstream conditions, then use the largest.
[2] 8 for Circular Stacks 12 to 24 inches
12 for Circular Stacks over 24 inches

Number of Traverse Points Used			
	Ports by		Across
	Pts Used		Required
☐	Particulate	☐	Velocity

Location of Traverse Points in Circular Stacks						
Traverse Point Number	(Fraction of Stack Diameter from Inside Wall to Traverse Point) Number of Traverse Points on a Diameter					
	2	4	6	8	10	12
1	.146	.067	.044	.032	.026	.021
2	.854	.250	.146	.105	.082	.067
3		.750	.296	.194	.146	.118
4		.933	.704	.323	.226	.177
5			.854	.677	.342	.250
6			.956	.806	.658	.356
7				.895	.774	.644
8				.968	.854	.750
9					.918	.823
10					.974	.882
11						.933
12						.979

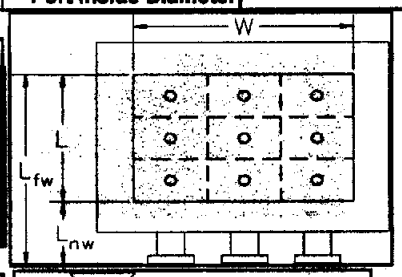
Traverse Point Locations			
Traverse Point Number	Fraction of Stack Diameter	Distance from Inside Wall	Distance Including Nipple Length
		m	m
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			

APEX INSTRUMENTS SOURCE TESTING EQUIPMENT

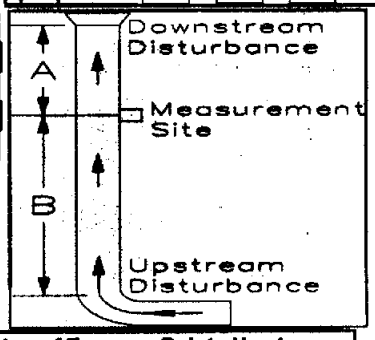
METHOD 1 - SAMPLE AND VELOCITY TRAVERSES FOR RECTANGULAR SOURCES

Plant Name		Date	
Sampling Location		Project #	
Operator		# of Ports Available	
Stack Type		# of Ports Used	
Stack Size		Port Inside Diameter	

Rectangular Stacks or Ducts			
Length to Far Wall of Stack	(L_{fw})		m
Length to Near Wall of Stack	(L_{nw})		m
(=Lfw - Lnw) Length of Stack	(L)		m
Width of Stack	(W)		m
(=2LW/(L+W)) Equivalent Stack Diam	(D_e)		m
(=LW/Cunits) Area of Stack	(A_s)		m^2



Distance from Port to Disturbances			
Distance Upstream	(B)		m
(=B/De) Diameters Upstream	(B_D)		diameters
Distance Downstream	(A)		m
(=A/De) Diameters Downstream	(A_D)		diameters



Number of Traverse Points Required			
Diameters to Flow Disturbance		Minimum Number of[1] Traverse Points	
Up Stream	Down Stream	Particulate Points	Velocity Points
2.00-4.99	0.50-1.24	25	16
5.00-5.99	1.25-1.49	20	16
6.00-6.99	1.50-1.74	16	12
7.00-7.99	1.75-1.99	12	12
>= 8.00	>=2.00	9 or 12[2]	9 or 12[2]
Upstream Spec			
Downstream Spec			
Traverse Pts Required			

[1] Check Minimum Number of Points for the Upstream and Downstream conditions, then use the largest.

[2] 9 for Rectangular Stacks 12 to 24 inches
12 for All Stacks over 24 inches

Number of Traverse Points Used			
	Ports by		Across
	Pts Used		Required
☐	Particulate	☐	Velocity

Traverse Point Number	Fraction of Stack Dimension	Distance from Inside Wall	Distance Including Nipple Length
		m	m
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			

Location of Traverse Points in Rectangular Stacks
(Fraction of Stack Dimension from Inside Wall to Traverse Point)

Traverse Point Number	Number of Traverse Points Across the Stack										
	2	3	4	5	6	7	8	9	10	11	12
1	.250	.167	.125	.100	.083	.071	.063	.056	.050	.045	.042
2	.750	.500	.375	.300	.250	.214	.188	.167	.150	.136	.125
3		.833	.625	.500	.417	.357	.313	.278	.250	.227	.208
4			.875	.700	.583	.500	.438	.389	.350	.318	.292
5				.900	.750	.643	.563	.500	.450	.409	.375
6					.917	.786	.688	.611	.550	.500	.458
7						.929	.813	.722	.650	.591	.542
8							.938	.833	.750	.682	.625
9								.944	.850	.773	.708
10									.950	.864	.792
11										.955	.875
12											.958

APEX INSTRUMENTS SOURCE TESTING EQUIPMENT

METHOD 2 - DETERMINATION OF STACK GAS VELOCITY AND VOLUMETRIC FLOW RATE

Plant Name		Date	
Sampling Location		Project #	
Operator		# of Ports Used	
Stack Type		Pitot Identification	
Pitot Leak Check	☐ PreTest ☐ PostTest	Pitot Coefficient (C_p)	

Stack Dimensions			
Diameter or Length of Stack	(D)		m
Width of Stack	(W)		m
Area of Stack	(A_s)		m^2

Pressures			
Barometric Pressure	(P_b)		mm Hg
Static Pressure	(P_{static})		mm H_2O
Absolute Stack Pressure	(P_s)		mm Hg

Stack Gas Composition			
Composition Data:	Actual ☐	Estimated ☐	
Carbon Dioxide Concentration	(%CO_2)		%
Oxygen Concentration	(%O_2)		%
Carbon Monoxide Concentration	(%CO)		%
Nitrogen Concentration	(%N_2)		%
Stack Moisture Content	(B_{ws})		
Stack Dry Molecular Weight	(M_d)		g/g-mole
Stack Wet Molecular Weight	(M_s)		g/g-mole

Results			
Avg Stack Gas Velocity	(v_s)		m/sec
Avg Stack Dry Std Flow Rate	(Q_{sd})		dscm/hr
Avg Stack Dry Std Flow Rate	(Q_{sd})		dscm/min
Avg Stack Wet Flow Rate	(Q_{sw})		ascm/min

Stack Cross Section Schematic

Velocity Traverse Data			
Run Number			
Run Time			
Traverse Point	Velocity Head (Δp)	Stack Temp (t_s)	Local Velocity $(v_s)_i$
	mm H_2O	°C	m/sec
$(\Delta p)^{1/2}_{avg}$ [1]			

[1] Average of the square roots of Δp
where $(\Delta p)^{1/2}_{avg} = {}^1/_n\Sigma(\Delta p^{1/2})$

Formulas Used

$A_s = DW/K_u$ for Rectangular Stacks

$A_s = (\pi(D/2)^2)/K_u$ for Circular Stacks

where $K_u = 1$ for metric units

where $K_u = 144$ (in^2/ft^2) for English units

$P_s = P_{bar} + P_{static}/13.6$

$\%N_2 = 100 - \%CO_2 - \%O_2 - \%CO$

$M_d = .44(\%CO_2) + .32(\%O_2) + .28(\%N_2 + \%CO)$

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

$(\Delta p)^{1/2}_{avg} = {}^1/_n\Sigma(\Delta p^{1/2})$

$T_{s(avg)} = {}^1/_n\Sigma t_s + T_u$

where $T_u = 273$ °K for metric units

where $T_u = 460$ °R for English units

$v_s = K_pC_p(\Delta p)^{1/2}_{avg}(T_{s(avg)}/(P_sM_s))^{1/2}$

where $K_p = 34.97$ for metric units

where $K_p = 85.49$ for English units

$Q_{sd} = 3600(1 - B_{ws})v_sA_s(T_{std}/T_{s(avg)})(P_s/P_{std})$

where $T_{std} = 293$ °K, $P_{std} = 760$ mm Hg, for metric units

where $T_{std} = 528$ °R, $P_{std} = 29.92$ in Hg, for English units

APEX INSTRUMENTS SOURCE TESTING EQUIPMENT

METHOD 3 - GAS ANALYSIS FOR THE DETERMINATION OF DRY MOLECULAR WEIGHT

Plant Name					Date		
Sampling Location					Project #		
Operator					# of Ports Used		
Fuel Type			Minimum Fuel Factor			Maximum Fuel Factor	
Orsat Leak Check	☐	PreTest	☐	PostTest	Orsat Identification		

Gas Analysis Data									
Run Number				Run Start Time			Run Stop Time		
Sample Analysis Time	Carbon Dioxide Volume (V_{CO2})	Oxygen Volume (V_{O2})	Carbon Monoxide Volume (V_{CO})	Carbon Dioxide Conc. ($\%CO_2$)	Oxygen Conc. ($\%O_2$)	Carbon Monoxide Conc. (%CO)	Nitrogen Conc. ($\%N_2$)	Dry Molecular Weight (M_d)	Molecular Weight Deviation (ΔM_d)
hh:mm	ml	ml	ml	percent	percent	percent	percent	g/g-mole	g/g-mole
Results			Averages						
Average Calculated Fuel Factor			$(F_o)_{avg}$			Molecular Wt Deviation < 0.3?			☐
Average Excess Air			$(\%EA)_{avg}$		percent	Fuel Factor in Handbook Range?			☐

Gas Analysis Data									
Run Number				Run Start Time			Run Stop Time		
Sample Analysis Time	Carbon Dioxide Volume (V_{CO2})	Oxygen Volume (V_{O2})	Carbon Monoxide Volume (V_{CO})	Carbon Dioxide Conc. ($\%CO_2$)	Oxygen Conc. ($\%O_2$)	Carbon Monoxide Conc. (%CO)	Nitrogen Conc. ($\%N_2$)	Dry Molecular Weight (M_d)	Molecular Weight Deviation (ΔM_d)
hh:mm	ml	ml	ml	percent	percent	percent	percent	g/g-mole	g/g-mole
Results			Averages						
Average Calculated Fuel Factor			$(F_o)_{avg}$			Molecular Wt Deviation < 0.3?			☐
Average Excess Air			$(\%EA)_{avg}$		percent	Fuel Factor in Handbook Range?			☐

Gas Analysis Data									
Run Number				Run Start Time			Run Stop Time		
Sample Analysis Time	Carbon Dioxide Volume (V_{CO2})	Oxygen Volume (V_{O2})	Carbon Monoxide Volume (V_{CO})	Carbon Dioxide Conc. ($\%CO_2$)	Oxygen Conc. ($\%O_2$)	Carbon Monoxide Conc. (%CO)	Nitrogen Conc. ($\%N_2$)	Dry Molecular Weight (M_d)	Molecular Weight Deviation (ΔM_d)
hh:mm	ml	ml	ml	percent	percent	percent	percent	g/g-mole	g/g-mole
Results			Averages						
Average Calculated Fuel Factor			$(F_o)_{avg}$			Molecular Wt Deviation < 0.3?			☐
Average Excess Air			$(\%EA)_{avg}$		percent	Fuel Factor in Handbook Range?			☐

Fuel Factor Fo		
Fuel Type	Minimum	Maximum
Coal, Anthracite	1.016	1.130
Coal, Lignite	1.016	1.130
Coal, Bituminous	1.083	1.230
Oil, Distillate	1.260	1.413
Oil, Residual	1.210	1.370
Gas, Natural	1.600	1.836
Gas, Propane	1.434	1.586
Gas, Butane	1.405	1.553
Wood	1.000	1.120
Wood Bark	1.003	1.130

Formulas Used
$\%CO_2 = V_{CO2}$
$\%O_2 = V_{O2} - V_{CO2}$
$\%CO = V_{CO} - V_{O2}$
$\%N_2 = 100 - \%CO_2 - \%O_2 - \%CO$
$M_d = .44(\%CO_2) + .32(\%O_2) + .28(\%N_2 + \%CO)$
$\Delta M_d = M_d - M_{davg}$
$F_o = (20.9 - \%O_2 - .5\%CO)/(\%CO_2 + \%CO)$
$\%EA = (\%O_2 - .5\%CO)/(.264\%NO_2 - (\%O_2 - .5\%CO))$

APEX SOURCE TESTING EQUIPMENT INSTRUMENTS

METHOD 4 - DETERMINATION OF MOISTURE CONTENT IN STACK GASES

Plant Name					Date	
Sampling Location					Project #	
Operator					# of Ports Used	
Stack Type					Meter Box Number	
Train Leak Check	☐	PreTest	☐	PostTest	Meter Cal Factor (Y)	

Moisture Content Data								
Run Number			Run Start Time			Run Stop Time		
Total Meter Volume	(V_m)		dcm	Barometric Press.		(P_b)		mm Hg
Avg Meter Temp	$(t_m)_{avg}$		°C	Stack Static Press.		(P_{static})		mm H_2O
Avg Stack Temp	$(t_s)_{avg}$		°C	Avg Orifice Press.		$(\Delta H)_{avg}$		mm H_2O
		Impinger 1	Impinger 2	Impinger 3	Impinger 4	Impinger 5	Impinger 6	Impinger 7
		ml	ml	ml	g	ml	ml	ml
Contents		DI	DI		Sil Gel			
Final Value	$(V_f),(W_f)$							
Initial Value	$(V_i),(W_i)$							
Net Value	$(V_n),(W_n)$							
Results								
Total Volume	(V_t)		ml	Water Vol Condensed		$(V_{wc(std)})$		scm
Total Weight	(W_t)		g	Water Vol Weighed		$(V_{wsg(std)})$		scm
Std Meter Volume	$(V_{m(std)})$		dscm	Sat. Moisture Content		$(B_{ws(svp)})$		%
Calc Moisture Content	$(B_{ws(calc)})$		%	Final Moisture Content		(B_{ws})		%

Moisture Content Data								
Run Number			Run Start Time			Run Stop Time		
Total Meter Volume	(V_m)		dcm	Barometric Press.		(P_b)		mm Hg
Avg Meter Temp	$(t_m)_{avg}$		°C	Stack Static Press.		(P_{static})		mm H_2O
Avg Stack Temp	$(t_s)_{avg}$		°C	Avg Orifice Press.		$(\Delta H)_{avg}$		mm H_2O
		Impinger 1	Impinger 2	Impinger 3	Impinger 4	Impinger 5	Impinger 6	Impinger 7
		ml	ml	ml	g	ml	ml	ml
Contents		DI	DI		Sil Gel			
Final Value	$(V_f),(W_f)$							
Initial Value	$(V_i),(W_i)$							
Net Value	$(V_n),(W_n)$							
Results								
Total Volume	(V_t)		ml	Water Vol Condensed		$(V_{wc(std)})$		scm
Total Weight	(W_t)		g	Water Vol Weighed		$(V_{wsg(std)})$		scm
Std Meter Volume	$(V_{m(std)})$		dscm	Sat. Moisture Content		$(B_{ws(svp)})$		%
Calc Moisture Content	(B_{ws})		%	Final Moisture Content		(B_{ws})		%

Moisture Content Data								
Run Number			Run Start Time			Run Stop Time		
Total Meter Volume	(V_m)		dcm	Barometric Press.		(P_b)		mm Hg
Avg Meter Temp	$(t_m)_{avg}$		°C	Stack Static Press.		(P_{static})		mm H_2O
Avg Stack Temp	$(t_s)_{avg}$		°C	Avg Orifice Press.		$(\Delta H)_{avg}$		mm H_2O
		Impinger 1	Impinger 2	Impinger 3	Impinger 4	Impinger 5	Impinger 6	Impinger 7
		ml	ml	ml	g	ml	ml	ml
Contents		DI	DI		Sil Gel			
Final Value	$(V_f),(W_f)$							
Initial Value	$(V_i),(W_i)$							
Net Value	$(V_n),(W_n)$							
Results								
Total Volume	(V_t)		ml	Water Vol Condensed		$(V_{wc(std)})$		scm
Total Weight	(W_t)		g	Water Vol Weighed		$(V_{wsg(std)})$		scm
Std Meter Volume	$(V_{m(std)})$		dscm	Sat. Moisture Content		$(B_{ws(svp)})$		%
Calc Moisture Content	(B_{ws})		%	Final Moisture Content		(B_{ws})		%

APEX SOURCE TESTING EQUIPMENT INSTRUMENTS

ISOKINETIC SAMPLING DATA

Plant Name		Date	
Sampling Location		Project #	
Operator		Run #	
# of Points Across		# of Ports Used	

Ideal Nozzle Diameter and IsoKinetic Factor Setup			
Pitot Tube Coefficient	(C_p)		
Avg Stack Temp	(t_s)		°C
Avg Gas Meter Temp	(t_m)		°C
DH @ 0.75 SCFM	($\Delta H@$)		mm H_2O
Avg Pitot Tube Diff. Pressure	(Δp_{avg})		mm H_2O
Stack Moisture Content	(B_{ws})		%
Stack Dry Molecular Weight	(M_{ds})		g/g-mole
Estimated Orifice Flow Rate	(Q_m)		acmm
DP to DH Isokinetic Factor	(K)		

Sampling Equipment			
Meter #			
Meterbox Cal. Factor	(Y)		
Nozzle #			
Actual Nozzle Diameter	(D_{na})		mm
Req. Nozzle Diameter	(D_{nl})		mm
Probe # / Length			m
Liner Material			
Sample Case / Oven #			
Impinger Case #			

Pressures			
Barometric Pressure	(P_b)		mm Hg
Stack Static Pressure	(P_{static})		mm H_2O
Absolute Stack Pressure	(P_s)		mm Hg
Absolute Meter Pressure	(P_m)		mm Hg

ΔV_m		Leak Checks			
Pre		m^3/min	@		mm Hg
Mid		m^3/min	@		mm Hg
Post		m^3/min	@		mm Hg
ΔV_m <		m^3/min	☐	Leak Check OK?	
Pitot OK?	☐		Orsat OK?	☐	

Traverse Point #	Sampling Time (Θ)	Clock Time	Dry Gas Meter Reading (V_m)	Velocity Head (Δp)	Desired Orifice ΔH (ΔH)	Actual Orifice ΔH (ΔH)	Stack Temp (t_s)	Probe Temp (t_{ml})	Meter Outlet Temp (t_{mo})	Filter Temp	Impinger Exit Temp	Pump Vacuum
	min	hh:mm:ss	m^3	mm H_2O	mm H_2O	mm H_2O	°C	°C	°C	°C	°C	mm Hg
Last Pt									Maximum Vacuum			
Average Values												

APEX INSTRUMENTS SOURCE TESTING EQUIPMENT

METHOD 5 - SAMPLE RECOVERY AND INTEGRITY DATA SHEET

Plant Name		Date	
Sampling Location		Project #	
Operator		Acetone Lot Number	

Run History Data				
Run Number				
Run Start Time				(hh:mm)
Run Stop Time				(hh:mm)
Train Prepared By				
Train Recovered By				
Recovery Date				(mm/dd/yy)
Relinquished By				
Received By				
Relinquished Date				(mm/dd/yy)
Relinquished Time				(hh:mm)

Equipment Identification Numbers			
Filter			
Acetone Wash			
Silica Gel			
Impinger Case			
Sample Box			
Oven			

Moisture Content Data					
Impingers 1, 2, and 3 - Water Volume					
Final Volume	(V_f)				ml
Initial Volume	(V_i)				ml
Net Volume	(V_n)				ml
Comments					
Impinger 4 - Silica Gel Weight					
Final Weight	(W_f)				g
Initial Weight	(W_i)				g
Net Weight	(W_n)				g
Comments					
Total Water Collected					
Total Volume	(V_{lc})				g

Formulas Used
$V_n = V_f - V_i$ $W_n = W_f - W_i$ $V_{lc} = V_n + W_n/\rho_w$ where $\rho_w = .9982$ g/ml

APEX INSTRUMENTS SOURCE TESTING EQUIPMENT

METHOD 5 - SAMPLE ANALYTICAL DATA SHEET

Plant Name		Date	
Sampling Location		Project #	
Operator		Acetone Lot Number	

Analytical Data								
Placed In Desiccator					Run Number			
		Number	Date	Time	Run Start Time			
Filter					Leakage Evident?	☐		
Acetone Wash Beaker					Estimated Volume			
		Filter	Acetone	Date	Time	Humidity	Temp	Cal Audit
		g	g	mm/dd/yy	hh:mm	%RH	°C	g
Measurement 1	$(m_{1f}),(m_{1a})$							
Measurement 2	$(m_{2f}),(m_{2a})$							
Measurement 3	$(m_{3f}),(m_{3a})$							
Measurement 4	$(m_{4f}),(m_{4a})$							

Results					Acetone Wash			
Final Weight	$(m_{ff}),(m_{fa}')$			g	Bottle Wt with Wash	(m_{bw})		g
Tare Weight	$(m_{tf}),(m_{ta}')$			g	Additional Rinse Wt	(m_{ar})		g
Weight Gain	$(m_f),(m_a')$			mg	Bottle Tare Weight	(m_{tb})		g
Blank Adjustment	(W_a)			mg	Net Wash Weight	(m_{nw})		g
Total Particulates	(m_n)			mg	Blank Concentration	(C_a)		mg/g

Analytical Data								
Placed In Desiccator					Run Number			
		Number	Date	Time	Run Start Time			
Filter					Leakage Evident?	☐		
Acetone Wash Beaker					Estimated Volume			
		Filter	Acetone	Date	Time	Humidity	Temp	Cal Audit
		g	g	mm/dd/yy	hh:mm	%RH	°C	g
Measurement 1	$(m_{1f}),(m_{1a})$							
Measurement 2	$(m_{2f}),(m_{2a})$							
Measurement 3	$(m_{3f}),(m_{3a})$							
Measurement 4	$(m_{4f}),(m_{4a})$							

Results					Acetone Wash			
Final Weight	$(m_{ff}),(m_{fa}')$			g	Bottle Wt with Wash	(m_{bw})		g
Tare Weight	$(m_{tf}),(m_{ta}')$			g	Additional Rinse Wt	(m_{ar})		g
Weight Gain	$(m_f),(m_a')$			mg	Bottle Tare Weight	(m_{tb})		g
Blank Adjustment	(W_a)			mg	Net Wash Weight	(m_{nw})		g
Total Particulates	(m_n)			mg	Blank Concentration	(C_a)		mg/g

Analytical Data								
Placed In Desiccator					Run Number			
		Number	Date	Time	Run Start Time			
Filter					Leakage Evident?	☐		
Acetone Wash Beaker					Estimated Volume			
		Filter	Acetone	Date	Time	Humidity	Temp	Cal Audit
		g	g	mm/dd/yy	hh:mm	%RH	°C	g
Measurement 1	$(m_{1f}),(m_{1a})$							
Measurement 2	$(m_{2f}),(m_{2a})$							
Measurement 3	$(m_{3f}),(m_{3a})$							
Measurement 4	$(m_{4f}),(m_{4a})$							

Results					Acetone Wash			
Final Weight	$(m_{ff}),(m_{fa}')$			g	Bottle Wt with Wash	(m_{bw})		g
Tare Weight	$(m_{tf}),(m_{ta}')$			g	Additional Rinse Wt	(m_{ar})		g
Weight Gain	$(m_f),(m_a')$			mg	Bottle Tare Weight	(m_{tb})		g
Blank Adjustment	(W_a)			mg	Net Wash Weight	(m_{nw})		g
Total Particulates	(m_n)			mg	Blank Concentration	(C_a)		mg/g

Formulas Used

m_{ff} = average of last two filter measurements

m_{fa}' = average of last two acetone measurements

$m_f = m_{ff} - m_{tf}$

$m_a' = m_{fa}' - m_{ta}'$

$W_a = C_a m_{nw}$

$m_{nw} = m_{bw} + m_{ar} - m_{tb}$

$m_n = m_f + m_a' - W_a$

APEX INSTRUMENTS SOURCE TESTING EQUIPMENT

METHOD 5 - DETERMINATION OF PARTICULATE EMISSIONS - RESULTS

Plant Name		Date	
Sampling Location		Project #	
Operator		Stack Type	

Historical Data						
Run Number					Average	
Run Start Time						hh:mm
Run Stop Time						hh:mm
Meter Calibration Factor	(Y)					
Pitot Tube Coefficient	(C_p)					
Actual Nozzle Diameter	(D_{ns})					mm
Stack Test Data						
Initial Meter Volume	$(V_m)_i$					m^3
Final Meter Volume	$(V_m)_f$					m^3
Total Meter Volume	(V_m)					m^3
Total Sampling Time	(Θ)					min
Average Meter Temperature	$(t_m)_{avg}$					°C
Average Stack Temperature	$(t_s)_{avg}$					°C
Barometric Pressure	(P_b)					mm Hg
Stack Static Pressure	(P_{static})					mm H_2O
Absolute Stack Pressure	(P_s)					mm Hg
Average Orifice Pressure Drop	$(\Delta H)_{avg}$					mm H_2O
Absolute Meter Pressure	(P_m)					mm Hg
Avg Square Root Pitot Pressure	$(\Delta p^{1/2})_{avg}$					$(mm\ H_2O)^{1/2}$
Moisture Content Data						
Impingers 1-3 Water Volume Gain	(V_n)					ml
Impinger 4 Silica Gel Weight Gain	(W_n)					g
Total Water Volume Collected	(V_{lc})					ml
Standard Water Vapor Volume	$(V_w)_{std}$					scm
Standard Meter Volume	$(V_m)_{std}$					dscm
Calculated Stack Moisture	$(B_{ws(calc)})$					%
Saturated Stack Moisture	$(B_{ws(sat)})$					%
Reported Stack Moisture Content	(B_{ws})					%
Gas Analysis Data						
Carbon Dioxide Percentage	($\%CO_2$)					%
Oxygen Percentage	($\%O_2$)					%
Carbon Monoxide Percentage	(%CO)					%
Nitrogen Percentage	($\%N_2$)					%
Dry Gas Molecular Weight	(M_d)					g/g-mole
Wet Stack Gas Molecular Weight	(M_s)					g/g-mole
Calculated Fuel Factor	(F_o)					
Fuel F-Factor	(F_d)					dscf/mmBtu
Percent Excess Air	(%EA)					%
Volumetric Flow Rate Data						
Average Stack Gas Velocity	(v_s)					m/sec
Stack Cross-Sectional Area	(A_s)					m^2
Actual Stack Flow Rate	(Q_{sw})					acmm
Wet Standard Stack Flow Rate	(Q_{sw})					wkscfh
Dry Standard Stack Flow Rate	(Q_{sd})					dscmm
Percent of Isokinetic Rate	(I)					%
Emission Rate Data						
Mass of Particulate on Filter	(m_f)					mg
Mass of Particulate in Acetone	(m_a')					mg
Mass due to Acetone Blank	(W_a)					mg
Total Mass of Particulates	(m_n)					mg
Stack Particulate Concentration	(c_s)					g/dscm
	(c_s)					gr/dscm
Particulate Emission Rate	(E)					kg/hr
	(E)					lbs/hr
	(E)					lbs/mmBtu
(Pt 75 App F Sect. 5.2.1) Heat Input	(HI)					mmBtu/Hr

APEX INSTRUMENTS SOURCE TESTING EQUIPMENT

Stack Sampling Procedure EV-070

Exhibit 2

Example Showing the Isokenetic Sampling Calculations

Example Showing the Isokenetic Sampling Calculations

Average of Square Roots of Δp_i

$$\left(\sqrt{\Delta p}\right)_{avg} = \frac{\sum_{i=1} \sqrt{p_i}}{n}$$

Average Δp

$$\Delta p_{avg} = \left[\sqrt{\Delta p_{avg}}\right]^2$$

Absolute Stack Pressure

$$P_s = P_b + \frac{P_g}{13.6}$$

Stack Gas Dry Molecular Weight

$$M_d = 0.44(\%CO_2) + 0.32(\%O_2) + 0.28(\%N_2 + \%CO)$$

Stack Gas Wet Molecular Weight

$$M_s = M_d(1 - B_{ws}) + 18.0B_{ws}$$

Stack Gas Velocity

$$v_s = K_p C_p \left(\sqrt{\Delta p}\right)_{avg} \sqrt{\frac{T_{s(avg)}}{P_s M_s}}$$

K_p = *85.48 (English Units)*
= *34.96 (Metric Units)*

Area of Stack (Circular)

$$A_s = \pi\left(\frac{D_s}{2}\right)^2$$

Area of Stack (Rectangular)

$$A_s = LW$$

Volumetric Flow Rate (acfm)

$$Q_a = 60 v_s A_s$$

Volumetric Flow Rate (scfm)

$$Q_s = K_1 v_s A_s \frac{P_s}{T_s}$$

Volumetric Flow Rate (dscfm)

$$Q_{sd} = K_1 (1 - B_{ws}) v_s A_s \frac{P_s}{T_s}$$

Dry Gas Meter Volume

$$V_{m(std)} = K_1 Y \frac{V_m (P_{bar} + \frac{\Delta H}{13.6})}{T_m} \quad \text{or} \quad = V_m Y \left(\frac{T_{std}}{P_{std}}\right) \frac{\left(P_{bar} + \frac{\Delta H}{13.6}\right)}{T_m}$$

K_1 = *17.64 (English Units)*
= *0.3858 (Metric Units)*

Volume of Water Vapor

$$V_{wc(std)} = K_2 (V_f - V_i)$$

K_2 = *0.04706 (English Units)*
= *0.001333 (Metric Units)*

Stack Gas Moisture Fraction

$$B_{ws} = \frac{V_{wc(std)}}{V_{m(std)} + V_{wc(std)}}$$

Pollutant Mass Rate

$$\overline{PMR_S} = c_S Q_S$$

Estimated Nozzle Diameter

$$D_{n(est)} = \sqrt{\frac{K_3 Q_m P_m \sqrt{T_s M_s}}{T_m C_p (1 - B_{ws}) \sqrt{P_s \Delta p_{avg}}}}$$

K_3 = 0.03575 (English Units)
= 0.6071(Metric Units)

K-Factor

$$K = \frac{\Delta H}{\Delta P} = K_6 D_n^4 \Delta H_@ C_p^2 (1 - B_{ws})^2 \frac{M_d T_m P_s}{M_s T_s P_m}$$

K_6 = 846.72 (English Units)
= 8.009×10^{-5} (Metric Units)

Meter Orifice Flowrate

$$\Delta H = K \Delta P$$

Average Moisture Content

$$B_{ws} = \frac{V_{wc(std)}}{V_{m(std)} + V_{wc(std)}}$$

Isokinetic Rate Percentage

$$\%I = \frac{K_s T_s V_{m(std)}}{P_s v_s A_n \theta (1 - B_{ws})}$$

K_s = 0.09450 (English Units)
= 4.320 (Metric Units)

Average Standard Flow Rate of Dry Stack Gas

$$Q_{sd(avg)} = 3600(1 - B_{ws(avg)}) v_{s(avg)} A_s \left(\frac{T_{std}}{T_{s(avg)}}\right)\left(\frac{P_s}{P_{std}}\right)$$

% Excess Air

$$\%EA = \frac{(\%O_2) + 0.5(\%CO)}{0.0264(\%N_2) - (\%O_2) + 0.5(\%CO)}$$

F_o Factor

$$F_0 = \frac{20.9 - \%O_2}{\%CO_2}$$

Nomenclature

A_n	Sampling Nozzle Cross-Sectional Area, mm^2 (in^2)
A_s	Stack Cross-Sectional Area, m^2 (ft^2)
B_{ws}	Moisture Fraction in Stack Gas, % H_2O
C_p	Pitot Tube Calibration Coefficient
$C_{p(std)}$	Standard Pitot Tube Calibration Coefficient
c_s	Particulate Concentration in Stack Gas, g/dscm gr/dscm (lb/dscf gr/dscf)
D_e	Equivalent Diameter, m (ft)
D_n	Sampling Nozzle Diameter, mm (in)
D_s	Stack Diameter
Δp	Stack Gas Velocity Pressure, mm H_2O (in H_2O)
$(\Delta p^{1/2})_{avg}$	Average of the Squareroots of Velocity Pressure, $(mm\ H_2O)^{1/2}$ $(in\ H_2O)^{1/2}$
%EA	Percent Excess Air, %
F_d	F factor for dry effluent, used with percent O_2, dry basis
F_o	Fuel Factor
$\Delta H_@$	Pressure Drop across Orifice Meter for 21.2 lpm (0.75cfm) at Std Conditions, mm H_20 (inH_2O)
ΔH	Pressure Drop across Orifice Meter, mm H_20 (in H_2O)
%I	Isokinetic Sampling Rate, %
K	Isokinetic Rate Constant
K_p	Pitot Tube Constant
K'	Critical Orifice Calibration Factor
L	Length of Duct Cross-Section at Sampling Site, m (ft)
m	Mass, g (lb)
M_d	Stack Gas Dry Molecular Weight, g/g-mole (lb/lb-mole)
M_s	Stack Gas Wet Molecular Weight, g/g-mole (lb/lb-mole)
pmr	Pollutant Mass Emission Rate, kg/hr (lb/hr)
P_b/P_{bar}	Barometric Pressure, mm Hg (in Hg)
P_s	Absolute Stack Pressure, mm Hg (in Hg)
P_{std}	Standard Pressure, 760 mm Hg (29.92 in Hg)
Q_{aw}	Actual Wet Volumetric Flowrate, acmm (acfm)
Q_{sd}	Dry Standard Volumetric Flowrate, dscmm (dscfm)
ρ_w	Density of Water, 0.9982 g/ml

θ	Time (minutes)
T_s	Stack Temperature, °C (°F)
T_{std}	Standard Temperature, 293K (528°R)
T_{amb}	Ambient Temperature, °C (°F)
V_{cr}	Critical Orifice Volume, m^3 (ft^3)
V_m	Dry Gas Meter Volume, m^3 (ft^3)
V_{lc}	Volume or Mass Liquid Collected in Impingers, ml or g
V_s	Stack Gas Velocity
W	Width of Duct Cross-Section at Sampling Site, m (ft)
Y	Dry Gas Meter Calibration Factor

Stack Sampling Procedure EV-070

Exhibit 3

ANSI/HPS Standard N13.1-1999:
Sampling and Monitoring Releases of Airborne Radioactive Substances from the Stacks and Ducts of Nuclear Facilities

ANSI/HPS N13.1-1999

Health Physics Society

An American National Standard

Sampling and Monitoring Releases of Airborne Radioactive Substances From the Stacks and Ducts of Nuclear Facilities

ANSI/HPS N13.1-1999

American National Standard –

Sampling and Monitoring Releases of Airborne Radioactive Substances from the Stacks and Ducts of Nuclear Facilities

Approved 12 January 1999
American National Standards Institute, Inc.

Abstract

American National Standard N13.1 sets forth guidelines and performance criteria for sampling the emissions of airborne radioactive substances in the air discharge ducts and stacks of nuclear facilities. Emphasis is on extractive sampling from a location in a stack or duct where the contaminant is well mixed. At such a location, sampling may be conducted at a single point. This standard provides performance-based criteria for the use of air sampling probes, transport lines, sample collectors, sample monitoring instruments, and gas flow measuring methods. This standard also covers sampling program objectives, quality assurance issues, developing air sampling action levels, system optimization, and system performance verification. Workplace, containment, and environmental air monitoring are not addressed. Specific sample analysis methods and the reporting or interpreting of results are also not addressed.

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Foreword (This foreword is not part of ANSI/HPS N13.1-1999.)

Monitoring of radionuclide emissions from stacks and ducts must provide results that are representative of the content and concentration of the gas stream as a whole. For extractive sampling, this requires that a sampling point must be in a region where the contaminant is well mixed with the bulk flow, and that the process of extraction does not bias the sample. In the 1969 version of ANSI N13.1, an attempt was made to meet the mixing goal by prescribing the location in a stack or duct where sampling could be performed in terms of the number of duct diameters from a flow disturbance. With the realization that in many circumstances conformance with a duct length rule would not in itself guarantee achievement of good mixing, another rule was recommended, namely that the extraction process be accomplished with multiple sampling nozzles in any stack or duct with a diameter greater than 150 mm (6 inches). The number of sampling points was dependent on duct diameter. Further, if aerosol particles with sizes greater than 2 to 5 μm could be present in the air stream, it was recommended that the inlet to the sampling nozzle be operated isokinetically. However, the use of multiple isokinetic nozzles to sample aerosol particles can be counterproductive. For a fixed sampling flow rate, as the number of sampling points is increased, the inlet diameter of each isokinetic nozzle is decreased, which causes larger losses in the entrance region of the nozzles. It is now known that the early rule-based approach (selection of an acceptable sampling location using a prescribed number of duct diameters from a disturbance, and on the requirement for multi-point isokinetic extraction of particulate samples) does not provide assurance that a sample will be representative.

This revision of ANSI N13.1 differs significantly from the earlier version in that it is now a performance-based standard rather than one based on prescriptive rules. There are two important aspects of performance addressed in the new approach. First, the concept of acquiring a representative sample is not based on rules for sample location and multi-point extraction, but rather on the premise that at any location where the contaminant concentration and the fluid momentum can both be demonstrated to meet numerical criteria for acceptable mixing, a representative sample can be obtained by extraction from a single point in that profile. Thus, the burden has properly shifted from specifying the distance that a sampling location must be from a disturbance to demonstrating compliance with numerical criteria placed on mixing performance. Second, numerical criteria are also used to provide the basis for a decision on whether a sampling system will deliver a representative sample to a collector or detector. Essentially the concept of isokinetic sampling has been replaced by numerical criteria for the sampling performance of extraction nozzle and transport line designs. By eliminating the requirement for multi-point isokinetic sampling and focusing instead on quantitative performance, the design of sampling systems with much lower sample losses is now possible. The complete set of numerical criteria has been shown to be achievable by a new generation of sampling system designs, and these criteria are expected to accommodate the application of any innovative concepts that are based on sound principles of aerosol physics and fluid mechanics. Although the approach to achieving representative effluent sampling presented in this standard represents a substantial departure from the methodology recommended by a previous version of this standard, it is practical and the expected performance is attainable.

This standard was written by a working group and interactively reviewed by a second group. Those who contributed to writing this version of the standard are:

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This standard was developed under the direction of the Health Physics Society Standards Committee and approved on 19 November 1996. At that time, the Standards Committee had the following membership:

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This standard was consensus balloted and approved by the ANSI-Accredited HPS N13 Committee on 4 June 1998. At the time of balloting, the HPS N13 Committee had the following membership:

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Sampling and Monitoring Releases of Airborne Radioactive Substances From the Stacks and Ducts of Nuclear Facilities

0 Introduction

ANSI/HPS N13.1 was first issued in 1969 as a guide to sampling airborne radioactive materials in the ducts, stacks, workplaces, and environs of installations where work with radioactive materials is conducted. Since then, an improved technical basis has been developed for each of the major sampling specialties. Consequently, the scope of this revision has been narrowed to directed airflow situations such as ducts and stacks.

This standard presents a new approach to representative sampling. The goal of achieving an unbiased, representative sample is accomplished by requiring that samples are extracted from airstreams meeting rigorous criteria for being well mixed for potential airborne contaminants. This standard sets forth guidelines and performance criteria for the proper use of air sampling nozzles, transport lines, sample collection and monitoring devices, and gas flow measuring methods in obtaining valid measurements of airborne radioactive materials in ducts or stacks. The guidelines and criteria presented in this standard are covered in the following clauses:

Clause 3 provides a glossary and nomenclature used in this standard to define terms and symbols that are used in the equations.

Clause 4 covers the objectives and approaches for sampling programs.

Clause 5 discusses the requirements for selecting sampling locations.

Clause 6 covers the requirements for designing the sampling system components.

Clause 7 describes the requirements of an acceptable quality assurance program specific for air sampling.

In addition, the following annexes provide information of use to sampling program and system designers:

Annex A provides techniques for measurement of flowrate through a stack or duct.

Annex B outlines modeling of particle losses in transport systems and presents an example of using a computer code to estimate aerosol penetration through a transport system.

Annex C presents special considerations for the extraction, transport, and sampling of radioiodine.

Annex D illustrates criteria for the selection of filters for collecting airborne radioactive particles.

Annex E describes the statistical basis of evaluating effluent sampling errors and uncertainty.

Annex F summarizes when to conduct sampling system performance verification and how this may be accomplished.

Annex G explains transuranic aerosol particulate characteristics and the implications for extractive sampling in nuclear facility effluents.

Annex H discusses tritium sampling and detection.
This standard does not cover:

a. the selection of sampling locations in work areas or containments;

b. selection of specific instrumentation for sample collection or on-line monitoring of collected samples;
c. the analysis of collected samples;
d. the reporting and interpreting results.

1 Scope

This standard sets forth guidelines and performance-based criteria for the design and use of systems for sampling the releases of airborne radioactive substances from the ducts and stacks of nuclear facilities.

1.1 Relationship to other standards

The potential applications of this standard are diverse, and consequently it is inappropriate to incorporate the many laws, regulations, and guidelines of governmental bodies that have an interest in the measurement of radioactive air emissions. It is incumbent on the user to be familiar with the applicable regulations.

1.2 Application of this standard

The requirements presented in this standard are aimed at sampling programs conducted for regulatory compliance. These requirements may not be universally applicable to all sampling programs, especially those with more limited objectives such as process control. When designing systems with objectives other than regulatory compliance, the designer should exercise professional judgement in the application of these requirements and should explicitly document the sampling objectives and the reasons for any exceptions to the requirements of this standard.

2 Normative references

The following standards and U.S. Environmental Protection Agency (EPA) test methods contain provisions that, through reference in this text, constitute provisions of this American National Standard. At the time of publication, the editions indicated were valid. All standards and EPA methods are subject to revision, and parties to agreements based on this American National Standard are encouraged to investigate the implications of the most recent editions of the standards and methods indicated below.

ANSI N13.2-1969 (Reaffirmed 1982), *Administrative Practices in Radiation Monitoring*, outlines administrative practices of a program for monitoring ionizing radiation, including gaseous effluents.

ANSI N42.18-1980 (Reaffirmed 1991) *Specification and Performance of On-Site Instrumentation for Continuously Monitoring Radioactivity in Effluents*, provides performance criteria for instrumentation used for monitoring radioactivity in liquid and airborne effluent streams. How effluent stream characteristics, operating environment factors, and standards and regulations affect the selection of instrumentation for effluent monitoring systems are briefly discussed. Dynamic range; sensitivity; accuracy; precision, physical, mechanical, and electrical requirements; and detection capability are also addressed. Testing procedures are not covered.

ANSI N320 (1979), *Performance Specifications for Reactor Emergency Radiological Monitoring Instrumentation*, addresses the essential performance parameters of monitoring instruments used during an accident event at reactors. The instrument operating environment, operational characteristics, and lower and upper detection limits are also addressed. The general instrument locations inside the reactor plant, at release points, and in the plant environs are addressed.

40 CFR 60, Appendix A, *Method 1, Sample and Velocity Traverses for Stationary Sources*, provides criteria for the number of points and conditions for velocity measurements.
40 CFR 60, Appendix A, Method 2, *Determination of Stack Gas Velocity and Volumetric Flowrate (Type S Pitot Tube)*, provides a methodology for flow measurements.

40 CFR 60, Appendix A, Method 2C, *Determination of Stack Gas Velocity and Volumetric Flowrate in Small Stacks or Ducts (Standard Pitot Tube)*, describes flow

characterization methodology for stacks and ducts less than 300 mm in diameter.

3 Glossary and nomenclature

A system for sampling radionuclides from a stack or duct can consist of several general components, as shown in figures 1a and 1b. A nozzle, placed at a location where a representative sample can be extracted, is used to remove the sample from the bulk flow stream. The transport line generally consists of tubing and connectors. Connectors can be bends, expansions, contractions, flow splitters, or mixing elements. Splitters are used where it is desired to extract a sample from the duct or stack with a single system and then to provide samples to multiple collectors or monitors. In some situations, a flow conditioning apparatus is used to dilute or concentrate a sample, or to selectively remove constituent gases (e.g., water vapor in order to minimize the risk of condensation). When a sampling system is used with a collector such as an aerosol filter, the sample may be analyzed in a laboratory that is remote from the sampling site. If a continuous monitor is used, the purpose of the monitor is to provide a near realtime signal of the concentration of the radionuclides of interest. The flow control system serves the function of providing the flow through the sampling system, of measuring that flow, and of maintaining its value at a desired level.

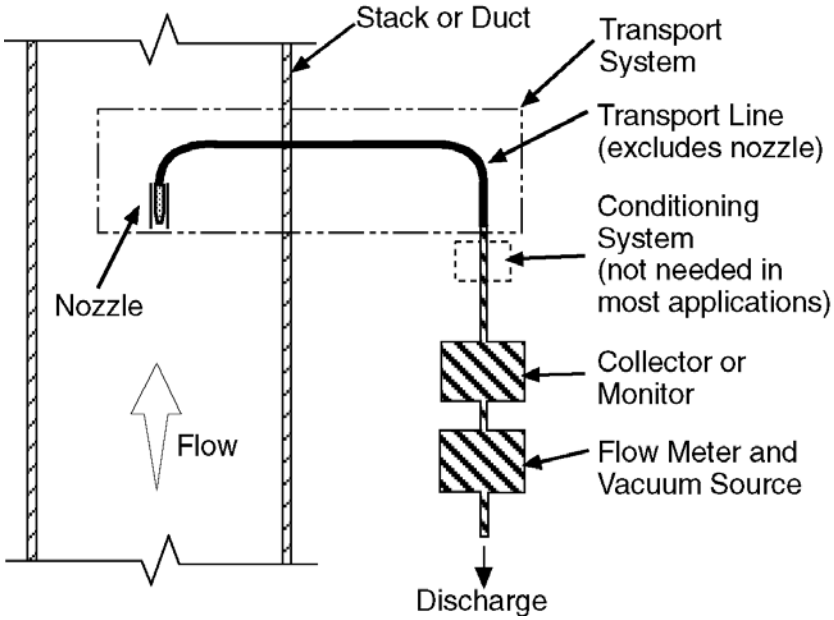

Figure 1a – Generic sampling system, illustrating a flow schematic where components are identified

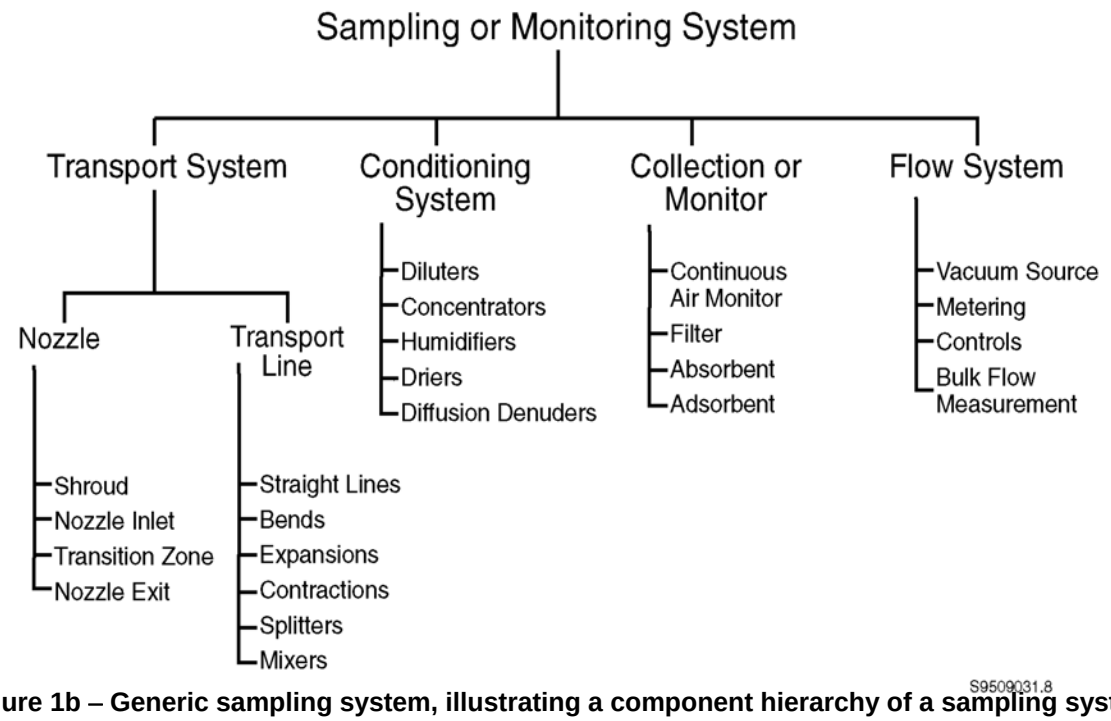

Figure 1b – Generic sampling system, illustrating a component hierarchy of a sampling system

3.1 Definitions

In this standard, the following definitions apply:

AD: See *Aerodynamic diameter*.

AMAD: Activity median aerodynamic diameter. The aerodynamic particle diameter for which 50% of the aerosol radioactivity is associated with sizes less than (or larger than) that particular size.

ANSI: Abbreviation for the American National Standards Institute, Inc.

ASME: Abbreviation for the American Society of Mechanical Engineers.

Accident (Conditions): Upset conditions that can lead to the release of abnormal concentrations of radionuclides from a stack or duct.

Accuracy: The closeness of agreement between a measured value and a true value.

Action Level: The threshold concentration of an effluent at which an appropriate action is to be performed.

Aerodynamic Diameter (AD): The AD of a particle of arbitrary shape and density is the diameter of a spherical water droplet that has the same sedimentation velocity in quiescent air as the arbitrary particle.

Aerosol: A dispersion of solid or liquid particles in air or other gas.

Aerosol, Monodisperse: An aerosol comprised of particles that are all of approximately the same size. In general, the geometric standard deviation of a monodisperse aerosol is less than or equal to 1.1.

Aerosol, Polydisperse: An aerosol comprised of particles with a range of sizes. In general, the geometric standard deviation of a polydisperse aerosol is greater than 1.1.

Analyzer: A device that provides for near realtime data on radiological characteristics of the gas (air) flow in a stack or duct. Usually, an analyzer will evaluate the concentration of radionuclides in a sampled air stream; however, some analyzers are mounted directly in a stack or duct, or are placed on the outside wall of the stack or duct, and have no flow through them.

Aspiration Ratio: Used in conjunction with the performance of a nozzle. It is the ratio of aerosol concentration at a nozzle inlet plane divided by the aerosol concentration in the undisturbed stream at the point where the nozzle is located.

Average Surface Roughness: A measure of the magnitude of fine irregularities of surface texture. The technical definition is the arithmetic average of the absolute values of the measured profile height deviations taken over a length of material and measured from the graphical center line. (See "roughness average" in ANSI/ASME B46.1-1985.)

Bend: A gradual change in direction of a sample transport line. The radius of curvature of a bend should be at least three times the inside diameter of the tubing.

Bulk Stream: The air flow in a stack or duct, as opposed to the sample flowrate.

Burial: The imbedding of a particle into a filter medium or the masking of a particle by subsequent deposits of particulate matter.

Calibrate: Adjustment of a system and the determination of system accuracy using one or more devices that are either traceable to the National Institute of Standards and Technology (NIST) or based on first principles. Includes adjustment of flow, temperature, humidity, or pressure gages and the determination of system accuracy using the NIST-approved or first-principles equipment.

CFR: Abbreviation for the Code of Federal Regulations.

Coefficient of Variation (*COV*): A statistic that is the ratio of the standard deviation of a variable to the mean value of that variable. It is usually expressed as a percentage.

Collector: A component of a sampling system that is used to retain radionuclides for analysis, e.g., a filter that is used to remove α-emitting transuranic or other radionuclide aerosol particles from a sample stream.

Concentrator: A device that is used to increase the concentration of contamination in a sample stream.

Conditioning System: Apparatus that could be used to purposefully, in a controlled manner, change the aerosol concentration, gas composition, particle size distribution, temperature, or pressure in a sample stream (see figure 1).

Confidence Interval: The statistical estimate of the bounds on a parameter that provides an interval that is expected, at a specified probability, to contain the true value of the parameter. For example, the 95% confidence interval will contain the true value 95% of the time.

Continuous Air Monitor (CAM): A near realtime sampler and associated detector, which provide data on radionuclides (e.g., concentration of α-emitting aerosol particles) in a sample stream.

Continuous Monitoring: Continuous near realtime measurements of one or more sampling characteristics.

Continuous Sampling: Either uninterrupted sampling or sequential collection of a sample obtained automatically at intervals short enough to yield results that are representative for the entire sampling period. The sample may be analyzed in near realtime (i.e., equivalent to monitoring) or it

may be analyzed post-sample-collection in a remote laboratory.

Control Equipment: Apparatus used to reduce contaminant concentration in the airflow exhausted through a stack or duct.

Curvature Ratio: The ratio of bend radius to the tube diameter.

Cutpoint: Used in conjunction with a device that causes a separation of aerosol particles by size. It is the aerodynamic particle diameter for which the device will collect 50%, and will transmit 50%, of the aerosol particles.

Depositional Losses: Loss of sample on the internal walls of a sampling system. See also *wall losses.*

Detection Limit: The minimum input signal to an instrument that can be said, with a predetermined confidence level, to exceed the inherent noise of the instrument.

Diffusion Denuder: A device that is used to selectively remove molecular constituents from a sample air stream.

Diluter: A mixing device that is used to reduce the concentration of radionuclides, background contamination, or water vapor in a sample stream. Usually, a sample stream taken from the stack or duct is mixed with dry filtered air in a diluter.

Dryer: A device for removing water vapor from a sample stream.

EPA: Abbreviation for the U.S. Environmental Protection Agency.

Effective Dose Equivalent: The sum of the products of the dose equivalent to the organ or tissue and the weighting factors applicable to each of the body organs or tissues that are irradiated.

Effluent: A waste stream flowing away from a process, plant, or facility to the environment. In this standard, the focus is on effluent air that is discharged to the atmosphere through stacks and ducts.

Emission: Contamination that is discharged into the environment.

Emit: The process of discharging contaminants into the environment.

Extractive Sampling: See “sampling.”

Fibrous Filter: A filter consisting of a mat of randomly oriented fibers.

Flowrate: The rate at which mass or volume of gas (air) crosses an imaginary cross sectional area in either a sampling system or a stack or duct. The rate at which volume crosses the imaginary area is called the *volumetric flowrate*; the rate at which mass crosses the imaginary area is called either the *mass flowrate* or the *volumetric flowrate at standard conditions*.

Fraction of Allowable Limit (FAL): A multiplier to be applied to an applicable state or federal dose limit for the purpose of developing a graded approach to sampling and monitoring. For each potential impact category, there should be a corresponding fraction of an allowable limit that provides a quantifiable basis for decisions regarding the required monitoring or sampling procedure.

Geometric Mean: If there are N observations of a random variable, x, the geometric mean of the sample, x_g is defined as:

$$\ln x_g = 1/N \sum_{i=1}^{N} \ln x_i$$

Geometric Standard Deviation: If there are N observations of a random variable, the geometric standard deviation, s_g, is calculated from:

$$\ln^2 s_g = 1/(N-1) \sum_{i=1}^{N} (\ln x_i - \ln x_g)^2$$

where x_g is the geometric mean of the random variable.

Grab Sample: A single sample removed from a flow stream over a relatively short interval of time.

Graded Approach (to Sampling): A decision process in which the requirements on the system vary with the risk of exposure to radionuclides.

HEPA (High Efficiency Particulate Air) Filter: A filter used for collecting aerosol particles from a flow stream. A HEPA filter collects at least 99.97% of aerosol particles of 0.3 μm diameter and is designed to collect greater fractions of aerosol particles with diameters either larger or smaller than approximately 0.3 μm.

Hydraulic Diameter: A parameter that is equal to the actual diameter of a circular stack or duct and is equal to (2 H W)/(H + W) of a rectangular stack or duct, where W = width of the duct cross section, and H = height of the duct cross section.

In-line: A system where the detector assembly is adjacent to, or immersed in, the effluent airstream.

Impaction: A process by which a particle or droplet is removed from an airstream by striking an object in the airstream. Curvature of air streamlines, principally on the front side of the object, cause particles with sufficient inertia to strike the object while the air flow passes around it.

Interception: A process by which a particle is removed from an airstream by an object in the flow, where the trajectory of the particle's center of gravity would miss the object, but the body of the particle strikes the object.

Isokinetic: A condition that prevails when the velocity of air at the inlet plane of a nozzle is equal to the velocity of undisturbed air in a stack or duct at the point where the nozzle inlet is located. *Anisokinetic* is the antonym of isokinetic. *Subisokinetic* refers to the condition where the nozzle inlet velocity is less than the free stream velocity. *Super-isokinetic* refers to the condition where the nozzle inlet velocity is greater than the free stream velocity.

LLD: Abbreviation for the lower limit of detection.

Laminar Flow: The flow regime in stacks or ducts associated with Reynolds numbers less than about 2200. This regime is not usually encountered in effluent air flows. Mixing in laminar flow results from molecular diffusion, which is a much slower process than mixing in turbulent flow.

Mass Size Distribution: A representation of the amount of mass of particulate matter associated with intervals of particle size, over the full size range encountered in a sample. For nuclear aerosol samples, it is a representation of the relative amount of mass (measured mass in a size interval divided by the total mass of the sample) associated with intervals of aerodynamic diameter.

MMAD: Mass median aerodynamic diameter. The aerodynamic particle diameter for which 50% of the aerosol mass is associated with all sizes smaller than (or larger than) that particular size.

May: In regulatory applications implies an action is not mandatory, but is permissible.

Membrane Filter: Filter media consisting of thin organic-based films having a range of selectable porosities and controlled composition. Thin porous metallic filters are sometimes also called membrane filters.

Micrometer: A unit of length equal to 1.0×10^{-6} meters that is commonly used to describe the size of an aerosol particle. It is abbreviated μm.

Mixer: A device that joins two or more sample streams to form a single sample stream. A typical example of a mixer is a Y-fitting where the flow enters the Y-fitting through the two arms of the Y and leaves through the single leg of the Y.

Mixing Element: A device placed in a stack or duct that is used to augment mixing of both contaminant mass and fluid.

Monitor: Measurement of the airborne radioactive constituent or the gross content of radioactive

material continuously, at a frequency that permits an evaluation of concentration in near realtime, or at intervals that comply with regulatory requirements.

NIST: Abbreviation for the National Institute of Standards and Technology.

Near Realtime: Repetitive or continuous measurement of sample properties.

Nozzle: A device used to extract a sample from an effluent flow and transfer the sample to a transport line or collection device. Within the nozzle there will be a transition zone where the sample stream adjusts to the conditions in the transport line.

Nozzle Exit (plane): An imaginary plane across the cross section of a transport system that divides the nozzle region from the transport line. Frequently, the nozzle is a separate component and the nozzle exit plane is clearly defined as the downstream end of that component. If there is no separate component, the nozzle exit is the end of the transition zone of the nozzle flow.

Nozzle Inlet (plane): The imaginary cross sectional inlet plane of a nozzle where the flow first enters the transport system. In the special case of a shrouded nozzle, the inlet is referenced to the inner nozzle rather than the shroud.

Number Size Distribution: A representation of the number of particles associated with intervals of particle size, over the full size range encountered in a sample. For nuclear aerosol samples, it is a representation of the relative number of particles (measured number of particles in a size interval divided by the total number of particles in the sample) associated with intervals of aerodynamic diameter.

Off-line: A system whereby a sample is withdrawn from the effluent stream and analyzed at a location that is remote from the region where the sampling system is located.

Off-Normal (Conditions): Conditions that are unplanned with unknown consequences. Examples are accidents and equipment failure.

Particle: An aggregate of molecules, forming a solid or liquid, ranging in size from a few molecular diameters to tenths of millimeters (several hundred micrometers).

Particle, Large: A large particle that has a size greater than 10 μm AD.

Penetration: The degree of passage of airborne contaminant through a transport system or transport line.

Potential Effective Dose Equivalent (PEDE): The effective dose equivalent of the most impacted member of the public from a source, which would occur if control equipment on that source were rendered ineffective. In this standard, PEDE is used as a decision tool.

Potential Emissions: Radionuclides that could be released to the environment from a stack or duct in the absence of control equipment.

Potential Impact Category (PIC): A ranking classification of potential radiological impact, based on factors such as potential effective dose equivalent (PEDE). It is used to implement a graded approach to sampling and monitoring. The potential for impact is based on facility source characteristics, assuming loss of containment of radioactive materials that would otherwise be released to the effluent stream under consideration.

Precision: The degree of agreement of repeated measurements of the same property, expressed in terms of the dispersion of test results about the mean result. A value of precision is obtained by repetitive testing of a homogenous sample under specified conditions. The precision of a method is expressed quantitatively as either the standard deviation computed from the results of a series of controlled determinations or as the coefficient of variation of the measurements.

Probe: A term sometimes used colloquially to refer to the equipment inserted into the stack or duct, usually a nozzle and part of the transport line.

Propagated Uncertainty: The uncertainty of a dependent variable of a measurement system as affected by the combined uncertainty of independent variables.

Quality Assurance: Planned and systematic actions necessary to provide confidence that a system or component will perform satisfactorily in service and that the results are both correct and traceable.

Radionuclide: An unstable isotope of an element that decays spontaneously, emitting radiation.

Rake: A probe within a stack or duct to which two or more nozzles are attached.

Record Sample: A sample that is collected for reporting purposes. Generally, record samples are analyzed off-line.

Reference Method: Apparatus and instructions for providing results against which other approaches may be compared. Application of a reference method is assumed to define correct results.

Representative Sample: A sample with the same quality and characteristics for the material of interest as that of its source at the time of sampling.

Sample: A portion of an airstream of interest, or one or more separated constituents, from a portion of an airstream.

Sample Extraction Location: The location in a stack or duct that coincides with the nozzle inlet. Generally, it is taken as a plane that is perpendicular to the longitudinal axis of a stack or duct.

Sampler: A device that collects or analyzes the sampled air flow from a stack or duct.

Sample Stream: Air that flows through a sampling system.

Sampling: The process of removing a sample of the flow stream in a stack or duct and transporting it out of the stack or duct for collection or analysis.

Sampling Environment: The condition of the flow and gas within a stack that can influence the sampling process. Factors include pressure, temperature, and molecular composition of the gas.

Sampling Location: See *sample extraction location*.

Sampling System: With reference to the diagram given in figure 1, a general sampling system consists of a probe, a transport line, a flow conditioning system, and a collector or monitor. Depending upon the application, a flow conditioner may not be used in the sampling system.

Sedimentation Velocity: The terminal (maximum) velocity an aerosol particle attains in quiescent fluid (air) as a result of the gravitational force.

Sensitivity: The change in reading of a mechanical, nuclear, optical, or electronic instrument as affected by changes in the variable being sensed by the instrument. The slope of a calibration curve of an instrument, where a calibration curve shows output values of an instrument as a function of input values.

Shall: In regulatory compliance means an action is mandatory.

Should: In regulatory compliance indicates an action is desirable but not mandatory.

Shroud: An aerodynamic decelerator placed about a sampling nozzle to reduce sampling biases.

Splitter: A device that divides a sample stream into two or more parts. The usual goal in the

design of a splitter is to have equal concentrations in each of the exit flows from the splitter.

Standard Conditions: Used to convert air densities to a common basis. The standard conditions adopted in this standard are a temperature of 25ºC and a pressure of 760 mm Hg.

Swirl: A condition when the velocity vectors of a flow are not aligned with the longitudinal axis of the stack or duct.

Transition Zone. A region in a transport system where the air flow characteristics change. For example, this could be the region where the sampled stream in the nozzle adjusts to the transport line geometry.

Transmission Ratio: Used in quantifying performance of nozzles. It is the ratio of aerosol concentration at the exit plane of a nozzle to the aerosol concentration in the undisturbed flow in the stack or duct at the point where the nozzle is located.

Transport Line: That part of a transport system between the nozzle exit plane and the entrance plane of a collector or analyzer.

Transport System: All components of a sampling system, excluding the collector or analyzer.

Turbulent Flow: The flow regime characterized by bulk mixing of fluid properties. For example, in a tube, the flow is turbulent if the Reynolds number is greater than about 3000 and laminar if the Reynolds number is below about 2200. There is little mixing in the laminar flow regime.

Uncertainty: An estimate of the deviation of a measured value from the true value of a parameter. Typically, the uncertainty is stated at a given statistical level of confidence (e.g., 95%).

Uncertainty Analysis: A procedure for estimating the overall impact on the accuracy or precision of a dependent variable as a result of estimated errors in independent variables.

Vapor: The gaseous form of materials that are liquid or solids at room temperature, as distinguished from non-condensible gases. (Vapors are gases but carry the connotation of having been released or volatilized from liquids or solids.)

Velocity Profile: A map of the velocity values at a given cross section in a stack or duct.

Volatile: Having a high vapor pressure that will allow significant quantities of material to become gaseous at the prevailing temperature. In this standard, the stack temperature would generally be considered as the reference.

Wall Losses: Loss of sample to the internal walls of a transport system. Quantitatively, it is the equivalent concentration lost to the walls of a nozzle, transport line, conditioning system, or transport system divided by the concentration at the inlet plane of the nozzle, transport line, or transport system.

3.2 Nomenclature

Symbols that are used in equations in this standard are defined below.

A Cross sectional area of a stack or duct, m^2

A_e Aspiration efficiency of a sampling nozzle, dimensionless

C Cunningham's slip correction for aerosol particles, dimensionless

C_{af} Velocity-averaging correction factor for determining flowrate in a stack or duct from a line average velocity taken with an acoustic flow meter, dimensionless

C_P Pressure coefficient for a pitot tube, dimensionless

C_{pt} Velocity-averaging correction factor for determining flowrate in a stack or duct

from a single point reading with a pitot tube, dimensionless

C_{ta} Velocity-averaging correction factor for determining flowrate in a stack or duct from a single point reading with a thermal anemometer, dimensionless

c_e Radionuclide concentration at the exit plane of a transport system component, mass or activity/m^3

c_i Radionuclide concentration at the inlet plane of a transport system component, mass or activity/m^3

c_∞ Radionuclide concentration in the undisturbed free stream at the nozzle location, mass, or activity/m^3

D_a Aerodynamic particle diameter, m or μm

De Dean number of a flow bend ($De = Re/R_c^{1/2}$), dimensionless

d_t Inside diameter of a transport system component (e.g., tube), m

L Length of a section of tubing, m

M Mean molar mass of a gas, kg/kmol

N Number of points or observations

P Overall penetration of sample through a transport system, dimensionless

P_j Penetration of sample through the *j*th component of a transport system, dimensionless

p Pressure, kPa or mm Hg

p_{std} Standard pressure, 101.3 kPa or 760 mm Hg

Q_T Total volume of gas (air) sampled, m^3

q Volumetric flowrate, m^3/s or liter/min

q_a Volumetric flowrate at actual temperature and pressure conditions, m^3/s or liter/min

q_{std} Volumetric flowrate at standard conditions (25° and 760 mm Hg), m^3/s

R Gas constant for a particular gas (R_u/M), kJ/(kg°K)

R_c Radius of curvature of a pipe bend, m

R_o Curvature ratio ($R_o = R_c/d_t$), dimensionless

R_u Universal gas constant, R_u = 8.314 kJ/(kmol•K)

Re Reynolds number of flow in a tube ($Re = \rho U_m d_t/\mu$), dimensionless

r Resuspension rate, $time^{-1}$ s^{-1}

S Signal

Stk Stokes number, $Stk = C\rho_w D_a^2 U_m/9\mu$, dimensionless

T Temperature, 1°C or K

T_a Temperature in stack or duct, 1°C or K

T_{std} Standard temperature, 25°C or 298 K

T_r Transmission ratio of a nozzle, dimensionless

t Time, s

U_m Spatial mean velocity of gas (air) in a flow tube, m/s

V Velocity, m/s

V_i Velocity at the midpoint of the *i*th element

V_{std} Equivalent velocity at standard conditions (25°C and 760 mm Hg), m/s

v_d Deposition velocity due to Brownian diffusion or turbulent inertial deposition on the wall of a transport tube, m/s

v_e Effective deposition velocity of contaminant at the wall of a transport tube, m/s

v_g Sedimentation velocity of an aerosol particle, m/s

Wl Wall losses of aerosols in transport system components, dimensionless

α Angular coordinate in a tube cross section, dimensionless

Δ Difference of two values of a parameter

η Efficiency, dimensionless

θ Time period over which sampling is performed, s

μ Dynamic viscosity of a gas, Pa s

ρ Density, kg/m^3

ρ_{std} Density of air at standard conditions (251 and 760 mm Hg), 1.184 kg/m^3

ρ_w Density of water at 4°C, 1000 kg/m^3

ϕ Angle of inclination of a tube axis relative to vertical, dimensionless

ε Surface roughness, m

λ Decay constant, s^{-1}

4 Objectives and approaches for sampling programs

A written technical basis shall be prepared for the programs and procedures to sample or monitor the releases of airborne radioactive substances from the ducts and stacks of nuclear facilities. Issues to be addressed shall include the sampling objective, the graded approach for meeting the objectives, the relevant facility operating conditions and airborne contaminants, and the action levels that signal changing conditions of significance. These issues set the bounds or parameters governing the overall design of sampling system placement, components, and operation as detailed in clauses 5, 6, and 7.

4.1 Defining the sampling objective

There are many possible objectives for an air sampling program. The rationale in choosing a specific objective and approach shall be well documented. Some possible air sampling objectives are:

a. meeting regulatory requirements;

b. assessing the need for a permanent sampling or monitoring program;

c. assisting in evaluating claims of radiation injury by workers or others;

d. measuring the release of radioactive materials to the environment through source sampling;

e. helping to ensure that people in the surrounding environment are not exposed to levels of airborne materials exceeding established limits;

f. helping to assess the possible consequences of non-routine incidents and guiding the selection of appropriate corrective action. This can include the integration of radioactive contamination released to the environment over various time periods.

Design of a technically defensible extractive sampling program (i.e., removing a portion of the effluent from the stream for subsequent detection or analysis) requires a clear understanding of these objectives. Many, but not all, objectives are related to worker or environmental protection and regulatory compliance. Failure to understand the sampling objectives can lead to inappropriate or ineffective system design and implementation. For

example, if exploratory sampling data are required to evaluate an uncharacterized or poorly characterized source, it may be appropriate to begin the evaluation using rugged portable equipment. Immediate use of highly sensitive or specialized equipment may lead to costly equipment damage or invalid results. At the same time, if long-term, repetitive sampling and monitoring data are required, efforts should be made to design systems with long-term reliability and ease of operation. The design and implementation of a sampling and monitoring plan for the ducts and stacks in a particular facility involve matters of engineering judgement in which conflicting demands arise from consideration of obtaining the most accurate sample, ensuring worker safety, physical plant constraints, and other operational and safety factors that have to be balanced.

The various objectives for sampling are not (or need not be) mutually exclusive in most stack sampling circumstances. A sampling system designed to meet one objective may meet other objectives as well. Likewise, there can be a number of approaches taken to achieve a given objective.

4.2 Developing a graded approach to sampling

The nature of an operation or process which creates the potential for airborne radioactive material influences the sampling program design and specific response to regulatory requirements. An operation or process being instituted for the first time may require more frequent and extensive sampling than one that is well understood. In addition, a program that requires more comprehensive monitoring is needed for a facility with an inventory of radioactive materials constituting a significant hazard than for a facility handling a less hazardous inventory.

4.2.1 Estimating potential emissions

A survey shall be conducted of the potential sources of radionuclide emissions at a facility to determine 1) the form and radiological inventory of materials being handled, 2) the potential extent of airborne dispersal of this inventory and resultant concentrations at the facility boundary in the event of accidental loss of filtration and control of stack emissions, 3) the potential effective dose equivalent that would be received by a member of the public if such a release occurs, and 4) a comparison of potential doses to appropriate regulatory limits.

Facility operators shall consider in their estimates of potential emissions and resultant public exposures, that under adverse conditions the facility effluent controls (e.g., filtration and gas holdup) may be completely eliminated. It would, therefore, be inappropriate to use actual measured or reported emissions from a stack as the basis for planning a sampling and monitoring program.

To estimate the potential emissions, it shall be assumed that all emission controls are ineffective. Therefore, the limiting factors determining the source term are the inventory, process throughput, and the physical form of the radionuclides being handled. A simple estimation method is the multiplication of the maximum expected radioactive material inventory by a factor that depends on the physical state of the material. The resultant source term can be input to a meteorological dispersion and dose estimation code for purposes of generating annual potential effective dose equivalent rates to a maximally exposed individual at the facility boundary. Table 1 (EPA, 1989) may be used as a guide to aid the estimation process.

Other approaches to estimating potential emissions might include the use of aerosol release fractions for the processes of concern, measurements of the material accumulated on the ventilation filters, or air sampling upstream of the ventilation filters (see DOE, 1994 and Barnett and Davis, 1996). In circumstances where the source term consists of a mixture of radionuclides, the radionuclides that contribute 10% or more to the total potential, or actual, effective dose equivalent from that source should be identified (or as otherwise required by regulation). Facility owners and operators should be aware that this procedure may be subject to state or federal regulation, and if

so, the requirements of such regulations shall supersede the proposed strategy.

4.2.2 A graded approach to sampling

A graded approach to establishing a sampling and monitoring program should be undertaken. For example, a sampling program design could be based on the potential that the effluent from a given facility has for contributing to offsite dose. This depends on whether the radioactive source materials being handled are easily dispersed (in gaseous form or finely divided powders), and also on their inherent radiological hazard. A facility stack that has the potential for discharging airborne radionuclides in quantities that could cause radiological doses to a member of the public in excess of a small percentage of federal dose limits would be a candidate for continuous sampling and trending and possibly also continuous monitoring with a sampler fitted with a realtime detector. The decision to utilize realtime monitoring in addition to continuous record sampling would be appropriate for stacks that present the potential for radiological doses well in excess of state or federal dose limits, and would also be appropriate where rapid detection of high levels of contamination during accidental releases is needed. Stacks that have the potential for release of radionuclides to the air in quantities that would contribute less than a small percentage of the regulatory dose limits would typically require only periodic confirmatory measurements.

Table 1 – Generalized strategy for estimating emissions for purposes of designing an appropriate sampling and monitoring program (EPA 1989)

Physical form or state of radioactive inventory available to release	Multiplicative factor to be used in estimating atmospheric emissions
Gases, condensable and noncondensable, and solids or liquids heated to a high enough temperature to be in a volatilized state	1.0
Liquids or particulate solids	0.001
Solids (other than above states)	1.0×10^{-6}

In the absence of a potential radiological source that could contaminate the effluent, no radioactive air emission sampling would be expected to be required, as in non-radiological stacks at nuclear facilities. However, the absence of a potential source would be subject to periodic review to verify that facility uses have not changed. A possible situation that should be guarded against is one in which a facility is no longer used for handling, storing, or processing radioactive materials, but has radiologically contaminated ductwork from previous work. Then maintaining the monitoring program may be well advised. Thus, a graded, four-tier program should be developed in which increasingly more sampling and monitoring resources are directed at stacks that have the greatest potential for causing public doses in excess of regulatory limits. Specific state or federal regulations appropriate to the type of nuclear facility stacks identified should be consulted to determine the appropriate basis for determining the potential for release and for dose limit thresholds for each tier. An example of a structure for a graded approach to determining required sampling and monitoring of emission points is shown in table 2. This approach employs potential impact categories (PICs) that represent dose consequences (e.g., potential effective dose equivalent) that may occur assuming effluent attenuation or filtration devices present in the effluent stream have no effect.

There is no one graded approach that would be appropriate for all facilities. The fractions of allowable dose limits proposed in table 2 are illustrative, and therefore shall be considered superseded by regulatory requirements. They exemplify how a dose limit standard can be associated with a graded approach to planning for sampling. As indicated, practical considerations involving such additional factors as worker safety and facility constraints should enter into the decision.

4.3 Considerations for different sampling situations

Particular attention should be given to the potential interactions between the operating conditions of the facility, the airborne contaminants, the ventilation components, and the sampling system. General considerations for assessing the interactions of facility operating conditions and the characteristics of the airborne contaminants are discussed in the following subclauses.

4.3.1 Considerations for sampling normal and off-normal conditions

Normal operating conditions are the expected conditions with an expected variability. These are usually the average operating conditions and their variance as defined in statistical terms. The normal operating conditions may have a large range of temperature and flowrates depending on the processes in operation. The effluent sampling system shall be designed to accommodate these conditions. The effluent discharge system may also operate with an effluent control (clean-up) system in place that reduces particulate and gaseous emissions to an acceptable level. Therefore, normal conditions exist for particle size and concentration and effluent reactivity and corrosivity. The effluent monitoring system shall be designed to reliably function under these operating conditions.

Table 2 – Graded approach to sampling and monitoring

Potential impact category	Monitoring and sample analysis procedures	Potential fraction of allowable limit
1	Continuous sampling for a record of emissions and in-line, realtime monitoring with alarm capability; consideration of separate accident monitoring system	> 0.5
2	Continuous sampling for record of emissions, with retrospective, off-line periodic analysis	>0.01 and ≤0.5
3	Periodic confirmatory sampling and off-line analysis	>0.0001 and ≤0.01
4	Annual administrative review of facility uses to confirm absence of radioactive materials in forms and quantities not conforming to prescribed specifications and limits	≤0.0001

Other expected operating conditions may exceed the design conditions for short durations. These conditions may occur during process changes or regular maintenance. Such changes of conditions should be considered design conditions if potential emissions during these periods are unlikely to exceed 10% of the total expected emissions. They should be considered off-normal conditions if they occur for only brief periods on an infrequent basis, such as once every six months, and are likely to involve more than 10% of the total expected emissions.

Off-normal conditions are generally considered to be unplanned with unknown consequences. They may result from:

a. Accidents such as fires, explosions, spills, or natural disasters;

b. Incidents, which are planned events whose outcomes were not fully anticipated or in which an accident or error altered the outcome; or

c. Equipment failures, which are events that alter the quality of the effluent, particularly such failures of the effluent clean-up system as leaking or damaged filters or loss of fluid to spray systems or traps.

Off-normal conditions may include the following:

a. Off-normal flow conditions (low or high flowrate in stack or duct);

b. Off-normal temperature conditions (high or low);

c. Off-normal gaseous constituents (corrosive, humid, condensing, vaporizing, high concentration, unknown composition);

d. Off-normal particle characteristics (high concentration, unusual particle shape, exceptionally large size).

Any one or a combination of these conditions may be possible and may alter the collection characteristics of the sampler. If any of these conditions are possible and probable, then the sample should accommodate the conditions or account for the effect and the resulting nonrepresentative sample. If necessary, a back-up system should be provided that can increase the range of sampling conditions.

An effluent sampling system should be able to accommodate or account for off-normal conditions. However, there are limits to the ability to accommodate and account for off-normal conditions, which may be expected to be reached well before the existence of the facility is threatened. Nevertheless, conditions of a low probability may occur that are markedly different from the expected conditions. These conditions may constitute a recognizable emergency or may result from an incident in which the consequences are recognized only after the fact. The effluent sampling system could be the only, or the most immediate, means for recognizing the incident or accident.

A sampling system that is capable of accommodating all off-normal conditions, due to its inherent design or because it is sufficiently controlled to alter its sampling characteristics to fit the altered sampling conditions, meets all requirements for off-normal conditions. A sampling system that requires a back-up system or a calculational algorithm to account for the off-normal conditions should monitor the off-normal conditions sufficiently to institute the back-up or to provide the necessary information for calculation. In any case, off-normal conditions may require alerting necessary personnel and instituting corrective actions in addition to obtaining a representative sample.

4.3.2 Sampling for aerosol particles

A representative sample of aerosol particles should not alter the radiochemical and physical characteristics so that analytical interpretation could be compromised. Special attention should be given to the design of the sampling nozzle and transport line so that excessive sample loss and discrimination between particles of various sizes are minimized. Detailed guidance for particulate extraction and transport line design is provided in clause 6.

Studies may be necessary to establish the size distribution and chemical nature of airborne particles in an effluent as an aid to the sample system design. Changes in the nature of effluent components should be anticipated with changes in operations. The possibility that appropriate sampling equipment modifications may be required should be kept in mind.

The sampling or monitoring system should be designed so that emissions occurring under accidental or off-normal conditions can be adequately sampled and detected. This is especially important if the effluent is filtered prior to discharge. Although the particle size most likely to directly penetrate HEPA (high efficiency particulate air) filter media is in the 0.1 - 0.3 μm diameter range, it is erroneous to assume that the sampling system need only be designed for sub-micrometer particles. Larger-size particles may be transmitted through HEPA filter banks due to small openings in HEPA frames, gasket seals, and filter media defects developing especially after extended periods of use. Downstream particle size distribution is primarily a function of the size distribution of the challenge aerosol (Scripsick 1994). When accidental or off-normal conditions occur, a wide range of particle sizes may be present in the effluent, and this shall be a factor in

the design. Particles well into the inertial size range (sizes larger than about 2 μm aerodynamic diameter, AD) should be considered to be present.

The off-normal case should consider the consequences of enhanced leakage of particles through filter media, filter seals, and cracks in filter frames. Thus, both normal and off-normal conditions may be characterized by chronic, low-level releases involving particles in size ranges covering nearly the full spectrum of sizes present in the challenge aerosol (Scripsick 1994). The accident case involves failures of potentially much greater consequence, in which high radionuclide concentrations may be present in the effluent. In either case, a polydisperse aerosol (an aerosol with a range of particle sizes) shall be anticipated. But the accident case is much harder to characterize in advance because changes in effluent discharge rate, added dust, smoke, and debris may be expected. However, it should be noted that particles greater than about 100 μm would not be expected to occur in large numbers in a stack effluent due to gravitational settling and inertial impaction removal effects during transport in the accident environment, and in the ductwork leading to the stack. The transport of such large particles in extractive sampling lines is exceedingly inefficient or nonexistent. Therefore, there are upper bounds to particle sizes that need to be evaluated. For typical stack conditions, evaluation with 10 μm AD particles should suffice; for the accident case, consideration of transport of somewhat larger particles is prudent. Annex G should be consulted for a discussion of the particle sizes associated with a variety of source terms and sampling concerns. The facility designer or evaluator should use modeling tools such as those discussed in clause 6 to understand the expected performance of any proposed sampling system under a variety of conditions.

A record sample is collected to minimize sample loss or bias created by complex sample transport line design or by realtime detector chamber design. Consideration should be given to the feasibility of collecting such a sample by means of an in-line sampler mounted directly in the stack flow rather than using an extractive system.

A continuous air monitor (CAM) provides near realtime detection of radionuclides in the effluent. It is usually desirable to design the sampler to collect as much of the largest size particles as feasible because of the increased activity associated with those large particles (see clause 4.3.3 for what is meant by "large particles," and annex G). However, if there is an unusually high concentration of inert large particles present along with radioactive particles, there may be an offsetting disadvantage to optimizing collection of large particles due to sample burial and radiation attenuation effects. Then, consideration of size-selective sampling techniques that discriminate against larger inert particles is warranted.

The system design chosen to supply aerosol samples to either a continuous air monitor or an in-line record sample filter (or both) shall be designed and evaluated to meet minimum performance objectives under normal, off-normal, and accident conditions with respect to the efficiency of particle transport to the filter, bias with respect to size or kind of particle, and allowable total random error. As discussed in the balance of this standard, performance objectives for these conditions will include many factors in addition to the central concern for providing a representative sample of the effluent.

4.3.3 Concerns for large particles

This document is primarily directed to sampling particles that pose inhalation risks. Thus, the particle sizes of major concern are generally less than or equal to 10 μm AD. If, however, there is a process or source feeding a sampled effluent that can release aerosol particles much larger than these sizes into the effluent stream, a special sampling apparatus located in the duct near the process should be designed that would reliably detect failure of emission controls on that source. The performance of such apparatus should be verified for the range of anticipated particle sizes and sampling conditions (e.g., stream velocity, mixing, etc.) at that location. As previously noted, use of HEPA filtration upstream of the sample withdrawal location does not eliminate all concerns

for large particles due to possible transmission through leaks in frames and seals. However, even nonfilterable radioactive gases and vapors may become associated with large particles by adsorption effects. For example, radioactive vapors or gases penetrating filtration can deposit on downstream stack or duct walls and become incorporated into surface layers, corrosion, or rust. Subsequent flaking or shedding of these layers may lead to the release of large radioactive particles that may go undetected by sampling systems that are optimized for collection of small particles. Alternate approaches to extra-large particle sampling may involve the periodic use of impaction plates or other specialized in-stack samplers or detectors to provide effective and timely samples and detection.

4.3.4 Sampling condensible vapors or reactive gases

The presence of radioactive air contaminants in the form of condensable vapors or reactive gases, such as certain forms of radioiodine, in the effluent stream will create a potential for serious distortions in the sample if precautions are not taken in the design and operation of the sampling system. Deposition in long transport lines and condensation due to temperature changes in the line should be avoided. The inner surfaces of the sampling probe and transport line should be constructed of or coated with nonreactive materials to minimize surface interactions with the sample. The possibility for conversion of a portion of the sample by chemical transformations induced by the sample transport process, such as conversion of molecular iodine gas into organic iodine vapor, should be understood and accounted for in the sampling system design. Conditioning the sample itself may be necessary, such as deliberately changing the temperature or purposefully diluting the sample with a carrier gas. The presence of non-radioactive constituents which could undergo phase changes that could cause loss or distortion of the sample, such as the condensation of water vapor, should also be taken into account in sample system design. Further discussion of special considerations related to sampling vapors and condensible gases is found in clause 6.

4.3.5 Sampling noncondensible, nonreactive gases

If the radioactive contaminant in the effluent stream is a noncondensible, non-reactive gas (e.g., ^{85}Kr), then it is not as critical to avoid long transport lines as it is for the other types of contaminants described above. In this instance, chemical or phase change interactions will not be a factor for system design.

4.4 Determining action levels

The action levels required of the air sampling system and program shall be considered as part of the design basis. The desired action levels determine the sensitivity requirements of the sampling system and affect design parameters such as sample volume, sampling frequency, the capacity of the collector, and the sensitivity of on- or off-line analyzers.

An action level is an effluent contaminant concentration threshold at which an appropriate action should be performed. The type of action performed depends on the circumstances. The action may entail generation of alarms, diversion of effluent through added effluent treatment, or intervention in the process creating the contaminant. There are inevitable consequences of whatever response is taken. Some are relatively minor, others are much more significant in terms of cost, damage to equipment, and possibly even human health and safety. Consideration shall be given to the setting of an action level for an effluent sampling or monitoring system that takes into account all such consequences. Not only can there be false negative outcomes (i.e., a true release of significance goes uninvestigated), but also false positive outcomes (i.e., worker responses to alarms, risks associated with rapid shutdown, and costs incurred needlessly). Both types should be anticipated, but, depending on the hazard potential of a particular stack effluent and other factors, false positive outcomes may be of more consequence to facility operations and worker safety than false negative ones due to work stoppage and evacuation of areas. Facility administrators should be cognizant of all reasonably anticipated outcomes.

The process of selection of an appropriate action level requires considering 1) the physical and chemical characteristics of the contaminant, 2) the characteristics of the sampling system required to obtain a sample of the contaminant for analysis and counting (e.g., the nozzle design characteristics, the transport line design, or sampling location), and 3) the type, intensity, and variability of interference with the measurement. Each of these considerations can contribute uncertainty to the contaminant concentration estimate, and, therefore, affect the level of confidence that can be assigned to the decision. The selection of an appropriate action level is separate from, and precedes, considerations of the required sensitivity of the sampling and measurement systems.

It is useful in the context of discussing action levels to draw distinctions among the following:

a. *Control monitoring:* Sampling for purposes of providing adequate warning so that an operator can take action to protect workers and the public from excessive exposure (i.e., continuous monitoring with alarm in Potential Impact Category 1 stacks of table 2);

b. *System availability:* Tracking sampling system availability and response so the facility operators are alerted if equipment failure takes a system off-line or seriously degrades performance;

c. *Performance sampling:* Regulatory compliance sampling that will yield data of such quality and type that the facility owner can identify and quantify the most significant radionuclides present in the effluent, and support demonstration of regulatory compliance by meeting all requirements for sample extraction location, instrument calibration and maintenance, sample handling, and chain of custody (this pertains to Potential Impact Categories 1, 2, and 3, table 2).

When determining action levels, consideration should be given to accuracy, precision, and uncertainty. These terms apply to both the process of sampling and the process of measurement. The concern for accuracy is directed at the elimination of bias in the sampling and measurement processes. Regular calibration of sampling and measuring equipment using accepted procedures and traceable standards is used to establish accuracy. Accuracy should be estimated at the 95% confidence level.

Statistical measures of dispersion of results about a measurement population mean are used to calculate precision. Sampling precision can be determined by replicate samples obtained under the same conditions. Measurement precision is obtained from the statistics of repeated measurements on replicate samples and by detailed analysis and propagation of errors in component measurements. Sampling and measuring precision are combined statistically to obtain an estimate of overall precision. The precision shall be estimated at the 95% confidence level. The concern of precision determinations is the estimation, and where possible, reduction of random errors in the sampling and measuring processes.

The departures of measured values from either the true values (accuracy effects) or from the mean of measured values (precision effects) are measures of error or uncertainty in the sampling and measurement system results. Contributions to uncertainty in sampling or measurement are best determined independently and combined by statistical propagation of error. A detailed discussion of sampling and measurement random errors, and error determination methods leading to an assessment of overall effluent sampling system uncertainty, is found in annex E.

Each facility should set data quality objectives for its particular sampling and measurement systems. A guide to recommended levels of uncertainty, as they pertain to accuracy and precision of sample extraction and transport, and of measurement, is given in table 3. Most of the recommendations for control monitoring in table 3 are not as stringent as the recommendations for record sampling. Near realtime radiation detection by a CAM, for example, usually cannot yield as accurate a measurement as would be expected of a laboratory counting system because variable bias

introduced by the presence of interfering background activity can often be significantly reduced or eliminated in the laboratory. Note that the accuracy and precision recommendations of table 3 are not meant to be absolutes and be equally appropriate in all cases and conditions. For example, effluents containing highly reactive constituents such as radioiodine may be particularly difficult to extract and transport without significant sampling bias, leading to higher estimated sampling accuracy uncertainties than 20%. In contrast, measurement accuracy in some systems may be easily held well below 20% given the characteristics of the instrumentation and measurement processes and should be so reported.

There may be justifiable reasons for sacrificing some degree of measurement accuracy in control systems to achieve higher instrument reliability, extended range of response, more effective background compensation, or other optimization goals. The overall system uncertainty limit values are derived by summing the respective relative variance estimates of the sampling accuracy or precision components. For example, the recommended limit of overall uncertainty in system accuracy for continuous monitors (40%) is the square-root of the sum of squares of the sampling accuracy component (20%) and the measurement accuracy component (35%) of uncertainty. Mentioning these components separately calls attention to the fact that if the sampling nozzle and transport line are not properly designed and properly placed, uncertainty will be created in sampling accuracy, and no amount of attention to measurement accuracy in the system will prevent the system from generating poor, biased data, and faulty alarm responses.

4.4.1 Action levels for control monitoring

The foregoing discussion provides a basis for incorporating accuracy and precision considerations in the setting of appropriate action levels. (There are no hard and fast rules concerning how these levels set.) It should be kept in mind that there is a trade-off between having high confidence in an alarm being triggered only by a 'true' contaminant release, and having sufficient alarm sensitivity to the presence of the contaminant, albeit at lower confidence. It is in this context that the true costs of false alarms have to weigh into the decision, along with the desire to detect the contaminant at the lowest concentration and shortest integrating time. In some CAM instruments it may be that the net counts are converted to activity concentration estimates by dividing the counts by detector efficiency, volume sampled, and time. All of these factors add uncertainty to the results. However, for alarming purposes, the largest uncertainty will typically derive from the counting error, as shown in annex E. If the costs of false alarms in an effluent monitoring system are large, then a decision may be made to set the alarm threshold at a relatively high level, and accept the risk of not detecting a lower level release in a timely fashion. In some contexts, trending of measurement results can be a useful tool to aid in maintaining control below a chosen action level. The user should determine an action level that can be attained, and design and operate

Table 3 – Guide to uncertainty of sampling and measurement

Factor or consideration	Record sampling	Control monitoring
Frequency of		
a) Sampling	Continuous	Continuous
b) Measurement	Weekly	Near realtime
Relative Uncertainty of Sampling		

System		
a) **Overall**		
Accuracy	±30%	±40%
Precision	±30%	±40%
b) **Sampling**		
Accuracy	±20%	±20%
Precision	±20%	±20%
c) **Measurement**		
Accuracy	±20%	±35%
Precision	±20%	±35%
System Availability	>95%	> 95%

the system so the detection limit for that sampling and measurement process is sufficiently below the action level, avoiding false alarms.

Control monitoring (using a CAM with alarm) does not imply that there can be a more relaxed attitude toward achieving a representative sample. In the case of continuous monitoring for particulate radioactivity in effluent streams, there may not always be sufficient small particles in a release to cause an alarm. Nor should it be assumed that in a poorly designed sampling system a few large particles will get through for alarming purposes. Such assumptions are ill-advised and unacceptable. The danger in lack of attention to CAM sampling system design and placement is that the component of the sample that is not well represented (possibly the larger size particles, for example) may be the very component that will provide the best chance for early warning, and hence control, worker protection, and impact limitation. The inherent limitations of providing radiation detection in the sampler during the sample collection process is due to the large background component in the detected signal. The choice of a relatively insensitive sampling system may lead to alarm thresholds consistent with an acceptable false alarm rate. However, the system may then be susceptible to excessive false negative responses.

4.4.2 Action levels for record sampling

If elevated concentrations of radioactive contaminants could be present in the effluent stream of high hazard stacks (PIC 1 of table 2), there shall be control monitoring. However, any stack that has the potential for radioactive emissions (PIC Categories 1 - 3) should have record sampling at an appropriate frequency. Record samples are collected continuously in an integrated sample, and then are analyzed by counting retrospectively (off-line). The levels of activity that can be detected by these means are typically many orders of magnitude smaller than those detectable by on-line monitors. Additional sensitivity can be achieved by compositing several week-long samples into monthly or even quarterly samples. The decision to attempt to achieve a certain detection limit goal will have to balance costs, time, and other factors. Uncertainty in the final estimate of quantities, concentration, and rates of emission will have to be propagated from errors in each of the factors entering into the respective calculation.

Another layer of analysis can be applied after determining the central estimates and their uncertainties, and logging them over time. Here the question is not whether a particular measurement is above the decision level for that contaminant, but whether a given trending in the data is normal or indicative of an off-normal condition, or whether a given datum is an outlier or is actually an elevated concentration. For this purpose certain statistical tests and trending procedures (e.g., control chart) are important. A retrospective action level may be set above the trend line in the data (say, at the 3σ level) to help decide whether a datum should be regarded as belonging to the family of normal values for the parameter being measured (e.g., the mean concentration of radioactivity emitted during the previous month or quarter), or belongs to a new, unidentified situation that requires investigation and intervention. The investigation could determine whether a bias had been introduced in the analytic procedure for radionuclide determination, or in the direction of ascertaining if a small leak exists in the filtration system of the facility stacks being sampled or monitored. The decision on the appropriateness of a given multiplier defining the action level will hinge on the estimated costs associated with either being wrong in concluding that an excursion beyond the action level has occurred, and that controls in a facility are breaking down (false positive), or being wrong about thinking that emission controls and analytic procedures are normal, only to discover later that chronic low-level releases have been undetected (false negative). If the achieved detection limit for a sampling system is well below the action level, there should be sufficient latitude to eliminate false negatives by trending.

4.4.3 System sensitivity needed to achieve selected action levels

Once an action level has been determined, another issue that shall be addressed is whether the proposed sampling or monitoring system is sufficiently sensitive (at the 95% confidence level). This is not a question of accuracy, but of whether a chosen system will be able to provide the needed net response above background. Assume that a particular effluent sampling or monitoring system or instrument has been operating in a given stack effluent long enough to establish the population of blank responses (meaning zero concentration of radioactive material of concern present, but varying levels of background activity are still present), large enough to reliably establish an estimate of the population mean of the blank, μ_B, and standard deviation, σ_B. While in operation, if there is no contaminant present, but there is an interfering background, the number of net counts S (gross counts - background counts) expected would have a limiting mean of zero, and a standard deviation of $\sigma_S = (\sqrt{2})\sigma_B$ (i.e., the variances in the gross and background counts are essentially the same). If the distribution of counts is approximately normal, then the upper 95% confidence level for the distribution of the net counts observed in the instrument will be $L_C(0.05) = 1.645\sigma_S = 2.33\sigma_B$. Such a level is often referred to as the decision level or the critical level of the measurement, because when the number of counts exceeds that level, there is only a 5% chance of making the error of concluding that

activity is present when there is truly only a background level present (a false positive). Note that the decision level is not the same as the detection limit or MDA level of the system. The decision level is an *a priori* number describing, in effect, the characteristics of the instrument and its operating conditions (levels of interference, counting time, etc), and not a measure of the uncertainty in a particular determination. If the decision level for a given proposed sampling or monitoring system is above the desired, or regulatory required level, a more sensitive system shall be developed.

Another type of error that can occur is that of falsely concluding that no activity is present when in fact there is significant radioactivity in the sample. One can define another limit, sometimes called the detection limit or lower limit of detection (LLD), as the mean number of net counts for which the observed net counts are 95% certain to exceed the decision level of the instrument. This avoids errors of the first kind (false positives) and also limits false negative errors. It can be shown that for a well-defined instrument background, and sufficiently large numbers of counts from the sample, the 95% detection limit, or LLD is

$$LLD = 2\ L_C(0.05) = 4.65\ \sigma_B \qquad (1)$$

The detection limit so defined is clearly also an *a priori* limit. The suitability of a proposed monitoring system to achieve a chosen alarm limit can be evaluated using the LLD concept. An alarm threshold set at the LLD, or 4.65 σ_B, or possibly larger will provide good immunity from false alarms (errors of the first kind). But it should be determined that it is not essential that sample counts near the critical level trigger an alarm (usually the case).

For example, assume that the standard deviation in a series of integrated count rates from a CAM is σ_B = 1 unit in relative terms with nominal background interference (typically radon daughter activity) present, but zero concentration of transuranic elements. Then if the alarm threshold set point is chosen to be 4 units ($4\sigma_B$), the probability of a false alarm when the target radionuclide concentration is zero is 3.2×10^{-5}. If the set point is increased to 6 units, the probability of false alarm in the presence of zero concentration drops to 9.9×10^{-10}. However, as the multiplier is increased, there is increased probability that low-level concentrations of contaminants will not trigger an alarm. Repeated counts as activity continues to accumulate on the sample filter should eventually result in an alarm or become apparent in data trending.

4.4.4 System performance and availability alarms

System performance and availability alarms are a separate consideration from action levels based on effluent releases. The sampling system designer shall consider the need for alarms activated by system component failure that results in the inability to properly sample. Such system failure alarms should be differentiated from alarms triggered by effluent release action levels because a very different response is needed. Establishing system failure alarms should be based on a statistical evaluation and consequence analysis considering acceptable levels of false positives and false negatives as discussed in clause 4.4.3.

System failure can take two forms. The first is a complete failure. Complete failure may be a system shutdown caused by an interruption of power or by the loss of a vital component. The complete failure should be indicated by an alarm to ensure that action is taken to restore operation. A complete failure that is due to the loss of a vital component may need a separate alarm for each mode of failure because the responses may be different. The importance of the alarm and the priority of response should be determined and entered into the facility alarm and response plan.

The second form is a partial failure that compromises the quality of the output, renders the output unusable, and causes the system to be inadequate for safety or regulatory requirements. This type of failure should require a system alarm and a graded response because there may be differences in operation that require instrument interpretation before activating an alarm. Two examples of partial failure are a significantly

reduced sample flowrate or a significant leak in the sample transport system. There are many other possibilities for partial failure, and it may be impractical to trigger alarms for them all. Consequently, there are requirements given for maintenance and inspections in clauses 6 and 7.

5 Sampling locations

5.1 Characterizing the sampling environment

The sampling environment within a stack or duct shall be characterized to design the sampling system for those conditions. A number of important parameters should be considered in the design process; however, accident or off-normal conditions shall always be kept in mind. Information used as a basis for design and location of sampling systems shall be fully and carefully documented.

5.1.1 Temperature

The expected temperature range at potential sampling points under normal operating conditions and credible accident conditions should be determined. Often the effluent temperature is very stable. There may be little seasonal variation in temperature as a result of controls in the facility heating, ventilation, and air conditioning operations. Off-normal conditions in many cases may have little effect on temperature; however, any temperature changes could be important to the collection of a sample under off-normal conditions.

5.1.2 Effluent flowrate

Knowledge of effluent flowrate is important in any final calculation of a release rate or a total release. The range of effluent gas velocities is also important in the design and control of the sampling system. The flowrate may change with a diurnal pattern as processes are increased or decreased, as fans are switched on or off for maintenance, as doors are opened or closed, or as heating and cooling systems are actuated. Off-normal conditions may include changing the effluent flow as a means of controlling or mitigating unusual process conditions. Facility design basis accident descriptions, and accident control and mitigation plans, may provide a basis for estimating changes in flow (including substantially reduced flow) as a result of accident conditions. These should be taken into account in the design of a sampling system for a particular facility. For example, the diversion of flow from one stack through an adjacent stack may be a control option that would be exercised if loss of HEPA filtration were to occur in the first stack.

5.1.3 Duct geometry

Duct geometry, including shape (circular or rectangular), main stack flow inlet conditions (e.g., side entry and angled entry at the base), additional lateral entry of contaminated flows, orientation of stack elements with respect to the vertical, and the presence or absence of such flow disturbance elements as bends can all be important factors in the design of proper sampling systems and their locations in the stack. The stack and duct geometry information shall be fully documented. Particular attention shall be given to the geometry of main flow entry conditions because in many cases the presence of angled inputs from fans or transition elements from rectangular to circular geometry can introduce non-axial velocity components in the flow that can result in swirl and irregularities in aerosol concentration profiles. Any discharge of a secondary flow of radionuclides into a main stack in a manner that injects contaminants into the boundary layer of the stack shall be recognized and avoided because this can result in contaminant releases that would not be well mixed with the bulk of the flow and, therefore, possibly not be detected.

5.1.4 Effluent composition

The composition of a stack effluent under both normal and accident conditions shall be taken into account when the design of a sampling system for that stack is developed. Radioactive contaminant characteristics that shall be considered are discussed in clause 4.3. Non-radioactive constituents shall also be identified whenever they

may influence the sampling system design. An important example is the presence of strong acid or caustic fumes that could cause rapid deterioration of a nozzle or sample transport line unless suitable compensation is provided by the selection of appropriate materials for construction of nozzles and lines. Inert dust loading in an effluent can also be a factor in the design of appropriate nozzles due to its potential for plugging inlets or interfering in the proper operation of sampling system elements. Moisture content of the effluent can also be a significant factor in the design of sampling systems due to possible interactions with contaminant components, condensation, and plugging of filters.

5.1.5 Particle size

The efficiency of extracting, transporting, and collecting sampled particles is sensitive to the size (AD) of the contaminant-bearing particles. Consequently, a knowledge of the contaminant particle size distribution under normal, off-normal, and accident conditions is important to the design of the entire sampling system and to the setting of reasonable performance expectations. Mass or activity size distributions shall be used rather than the number size distribution. Size information can often be estimated for normal and off-normal conditions; however, estimates for accident conditions are more tenuous. Rodgers (1995) suggests that for most applications, a particle size of 10 μm AD is appropriate to use in design and evaluation of sampling systems, for both normal and off-normal conditions. Accordingly, the system design should be based on an assumed particle size of 10 μm AD unless there is evidence that a significant fraction of the aerosol mass or activity will be associated with larger sizes. In the latter case the design and testing should proceed on the basis of an assumed largest AD particle size or a size for which not more than a specified percentage (e.g., 10%) of radioactivity could be assumed to be associated with all sizes larger than that size. For further discussion on particle size as applied to system design, see annex G.

5.2 Selection of sampling sites

5.2.1 General considerations

Locating a site in a stack or duct where a representative sample can be obtained by extractive methods involves such considerations as the characteristics of the radioactive contaminant, factors associated with equipment placement and support, and worker health and safety. Generally, the sample extraction location should be situated between the discharge plane of a fan and the stack exit plane, with caution that the location should not be so close to the stack exit plane that wind effects can significantly influence the velocity profile at the sampling location. In addition, the sampling location should be in a region where the contaminant profile is well mixed and stable, it should be readily and safely accessible, it should not present a problem for sampling services and maintenance activities, and it should be able to accommodate analysis or collection equipment that does not compromise the quality of the sample.

High radiation fields under post-accident conditions may present a problem with respect to worker safety at the sample extraction location. High ambient temperatures may also be a problem in some cases. Either of these situations may dictate longer transport lines than normally needed to accommodate installation of the sample collection and detection equipment at a properly shielded and air conditioned location; however, sampling lines should be of a minimum length to reach such a location.

If the contaminants are in the form of condensible vapors or reactive gases, long transport lines and large temperature changes in the sample or the transport line shall either be avoided or measures shall be taken to minimize potential loss of sample. Heat tracing of the transport line is readily accomplished, but conditioning of the sample may be necessary, such as a deliberate temperature change and purposeful dilution with a carrier gas.

In the case of particulate contaminants, the concerns about losses to the walls of the transport lines dictate keeping sample lines short. Abrupt temperature changes and abrupt cross-sectional reductions also should be avoided. The sampling

location should be such that these constraints can be accommodated. This usually requires that the analysis or collection components be located near an acceptable sample extraction point, where the latter is chosen on the basis of completeness of particle mixing in the effluent stream. The attendant environmental requirements for the collection or analysis system should be applied. Previously described worker safety issues, which are related to high temperature and radiation fields, also apply. Concern for worker exposure to hazardous conditions may also arise when considering whether a transport line system can be made shorter or simpler to avoid particle losses. A potential exists for conflicting concerns in such decisions.

Guidance in the following sub-clauses is primarily directed towards sampling from stacks or ducts that have continuous flows. However, there are situations where the flow is not continuous (e.g., gas vented during the process of filling a tank) or where the duct size may be too small to accommodate sampling equipment. In such situations, consideration should be given to the collection of contaminants from the entire stream and treating the entire stream as the sample. Also, there may be situations where the entire flow through a stack or duct is sufficiently small that the entire stream can be drawn through the sampling system. For these cases, it is not necessary to qualify the sampling location.

5.2.2 Qualifying the sample extraction location

Because the intent of sampling and monitoring stack effluents is measurement of contaminant discharge from the source, the sample extraction process should occur downstream of all inputs and control equipment. Within constraints imposed by more general considerations of an extraction site location on a stack, the site shall be chosen to provide a valid representative sample of the entire contaminant discharge. Bends, fans, and duct junctions may produce distortions in velocity and contaminant profiles and may introduce angularity in the flow that can adversely affect sampling nozzle performance. Therefore, such locations should be avoided.

5.2.2.1 Angular or cyclonic flow

At the proposed sampling location, the flow of particles and gases shall not exhibit excessive angularity or swirl. The presence of swirl can adversely affect the mixing of particles in the effluent and degrade the performance of a sample nozzle. The criterion of acceptability is that the average flow angle shall not exceed 20 degrees (relative to the longitudinal axis of the stack or duct). An appropriate method for determining if a proposed location meets this criterion is described in 40 CFR 60, Appendix A, Method 1, Section 2.4, "Verification of the Absence of Cyclonic Flow." If there is excessive flow swirl, it can be corrected by using internal elements placed in the stack or duct. In the past it was common practice to use either honeycomb or parallel plate flow straighteners.

However, such elements should be used only after suitable mixing of contaminants has been achieved. In some situations excessive flow swirl can be eliminated through the use of static flow mixing elements rather than flow straighteners.

5.2.2.2 Contaminant concentration and velocity profiles

If aerosol particles can be present in the flow, the criterion for establishing the acceptable uniformity of contaminant mixing and velocity across a stack or duct is that the coefficient of variation (*COV*, the standard deviation as a percentage of the mean) of concentration of 10 ± 1 μm AD tracer aerosol particles and of a tracer gas (e.g., helium, sulphur hexafluoride) shall be less than or equal to 20% across an area that encompasses at least the center two-thirds of the cross-sectional area of the stack or duct. Measurement points at the candidate sampling location should be selected in accordance with 40 CFR 60, Appendix A, Method 1. The traverse points for velocity (figure 1-2) in Method 1 shall be used for measurements with both tracer gas and aerosol particles. Similarly, the *COV* of stack gas velocity shall be within ±20% across the center two-thirds of the area of the stack or duct. The points for velocity measurements shall also be those given in figure 1-2 of Method 1. It may be necessary to either

add additional traverse points or to adjust the points in Method 1 for velocity, tracer gas, or aerosol mapping at the boundary demarcating 2/3 of the cross sectional area of the stack or duct. Also, points may need to be adjusted because of limitations of Method 1 on the proximity of a sampling point to a wall.

If only gaseous contaminants can be present, an additional criterion beyond that for aerosol particles must be met. Anomalously high concentrations of gases or particulate matter could occur near the wall in a stack flow if contaminant is injected into the near-wall region of the flow boundary layer. Accordingly, an additional mixing criterion is that at no point in a complete grid for velocity setup in accordance with 40 CFR 60, Appendix A, Method 1, shall the concentration of tracer gas be any higher than 30% above the mean concentration value in that sampling plane. Because of possible limitations due to the physical size of a particle sampling nozzle, the measurement of the concentration of 10 μm AD aerosol particles may be difficult and subject to errors in the vicinity of the wall of a stack or duct. Consequently, the 30% criterion is not applicable for aerosol particles. A summary of the acceptance criteria for a sampling location is given in table 4.

The above criteria for uniformity are selected to reflect the reality of experimental errors expected in sampling from stacks in the field. The 10±1 μm AD test aerosol particle diameter was selected because of the need for a test aerosol whose aerodynamic behavior clearly exhibits inertial effects that could adversely influence mixing; because it has been previously used in the performance specification of sample nozzles and transport lines (Rodgers 1987; McFarland et al. 1989); because it is relatively easily generated in either monodisperse (single particle size) or polydisperse forms and released into stack flow; and because it can be present in stacks and ducts of the nuclear industry (Rodgers 1995). In some cases, it may be necessary to use a larger particle size as a basis for the criterion (see all of clause 4.3 and subclause 5.1.5).

Often nuclear facilities have multiple stacks or ducts that are of similar design. For such situations, it is not necessary to completely test the sampling location in a candidate stack or duct for compliance with the requirements given in clause 5.2.2 provided that:

1) A geometrically similar stack or duct (one with proportional critical dimensions) has been tested and the sampling location has been found to comply with the requirements of clause 5.2.2. Critical dimensions are those associated with components of the effluent flow system that can influence the degree of contaminant mixing and/or the velocity profile. The prior testing may be conducted either on a tack or duct in the field, or it may be conducted on a scale model.
2) The product of mean velocity (see eqn A-2) times hydraulic diameter of the candidate stack or duct is within a factor of six of that of the tested stack or duct, and the hydraulic diameter of the stack or duct is at least 250 mm at the sampling location. The Reynolds numbers based on hydraulic diameter of both the candidate stack or duct and the tested stack or duct are greater than 10,000 (see eqns B-1 and B-2 for examples of expressions that can be used for calculation of Reynolds numbers).
3) The velocity profile in the candidate stack or duct meets the requirements of clause 5.2.2.2.
4) The difference between velocity *COV*s of the two systems is not more than 5%.
5) The sampling location in the candidate stack or duct is placed at a geometrically similar location to that in the tested stack.

If these requirements are fulfilled, the sampling location in the second stack or duct is acceptable.

If the requirements of clause 5.2.2 are met, sampling may be conducted at a single point. The nozzle shall be placed within the center one-third of the cross sectional area of the stack or duct at the qualified location.

Other approaches may be used to qualify a location for single point sampling provided the accuracy of the methodology is equal to, or exceeds, that based on the criteria given herein.

For example, in an application dealing with sampling of radioactive gases it may be possible to inject a tracer gas into the stack at a known mass flow rate. If the mass flow rate of tracer emitted from the stack based on use of a single point sampler at a candidate location were to show a value within ±20% of the mass flow rate of injected tracer, the sampling location could be considered acceptable. In such a situation it may be necessary to demonstrate the quality of samples acquired at different stack gas flow rates (e.g., average, high and low).

5.3 Methods for qualifying the sample extraction location

To meet the contaminant mixing criteria given in clause 5.2.2, it is necessary to verify that the stream is well mixed or otherwise sufficiently described to establish that a sample of the effluent will be representative. When tests are conducted with a tracer gas (e.g., sulfur hexafluoride) the gas should be introduced downstream of the last location at which contamination can enter the effluent stream. If there is a fan that draws air from ducts equipped with air pollution control equipment (e.g., HEPA filters), and subsequently discharges the air into the stack or duct, the injection location can be between the control equipment and fan. Tests should be run with a tracer introduced at five or more locations across the cross section of the air stream. However, if a stack needs to be tested for both particles and gases, the same injection location would generally be used for both types of tests. For a rectangular duct, the injection shall be at the center and near each corner (at or within a distance of 25% of a hydraulic diameter from a corner). For a round duct, the introduction shall be at the center and near the wall (within 20% of a diameter from the wall). For tests conducted with a tracer gas injected upstream of a fan, the gas only needs to be introduced at a single point (e.g., the center of the duct). Sampling of the tracer gas shall be conducted across the cross sectional plane at the proposed sampling location. The tests should be conducted while the stack flowrate is approximately the same as the expected normal flowrate.

The degree of mixing for aerosol particles shall be tested with particles of 10 ± 1 μm AD, or other selected size if there can be a significant fraction of the aerosol mass or activity associated with sizes larger than 10 μm AD. The aerosol may be introduced at only one location, which is at the center of a stack or duct as far upstream as possible of the sampling plane, yet downstream of feeder ducts, fans, and air pollution control equipment. As in the case of a gas, the particles are demonstrated to be well mixed by sampling

Table 4 – Summary of acceptance criteria for a sampling location

Characteristic	Methodology	Acceptance Criteria
Measurement to determine if flow in a stack or duct is cyclonic.	40CFR60, Appendix A, Method 1	The average resultant angle shall be less than 20°.
Velocity profile in a large duct (> about 0.3 m diameter) and small stacks and ducts (< about 0.3 m).	Select traverse points from 40CFR60, Appendix A, Method 1 (figure 1-2) for the center 2/3 of the area of the stack or duct. Additional points or area may be needed to adequately cover the region.	COV shall not exceed 20% over the center region of the stack that encompasses at least 2/3 of the stack area.
Tracer gas concentration profiles in large and small stacks and ducts.	Select traverse points from 40CFR60, Appendix A, Method 1 (figure 1-2) for the center 2/3 of the area of the stack or duct. Additional points or area may be needed to adequately cover the region.	COV shall not exceed 20% over the center region of the stack that encompasses at least 2/3 of the stack area.
Maximum tracer gas conc-entration in large and small stacks and ducts.	Select traverse points from 40CFR60, Appendix A, Method 1 (figure 1-2) for the entire cross sectional area.	The maximum value of tracer gas concentration shall not exceed the mean value by more than 30% of the mean value at any point on a complete Method 1 set of velocity traverse points.
Aerosol particle concentration profile in large and small ducts.	Select traverse points from 40CFR60, Appendix A, Method 1 (figure 1-2). Additional points or area may be needed to adequately cover the region.	COV shall not exceed 20% over the center region of the stack that encompasses at least 2/3 of the stack area.

over the cross section at the proposed sampling location.

Testing to establish the degree of mixing requires sufficient gas or particles to provide an adequate signal at the extraction point. The method of detection and its detection limit are the important considerations in the amount of material introduced. Sufficient material shall be introduced to be detectable after dilution in the effluent stream. Examples of methodologies for obtaining data on velocity, tracer gas, and aerosol profiles are given by Rodgers et al. (1996).

It is essential to establish confidence that a chosen location for sample extraction based on demonstrated complete mixing using the above methods and criteria will continue to meet mixing performance requirements under changed conditions relative to those at the time of testing. Historical records of effluent flows can be used to

provide evidence of extremes (high or low) of flows that might be encountered in a stack. Calculations of expected flows under accident conditions or very different operating modes can be based on documented engineering judgement. Mixing under flowrates that are considerably different from normal may be substantiated by tests with models or field testing of the stack or duct. Under most conditions, changes in flow rate will not significantly affect the mixing. In general, if the flowrate increases, acceptable mixing will not be degraded; however, if the flow rate were to be reduced to the point where laminar conditions were approached, there could be a major degradation in mixing effectiveness. This event would generally only be possible with a very small cross section stack or duct, such as a tank vent. If this is possible, the flow system should be modified to preclude the onset of near-laminar conditions.

5.4 Sampling locations other than final effluent streams

Sampling may be required at locations upstream of the final exhaust discharge point for purposes of observing process conditions, personnel protection, or aiding the interpretation of measurements of the final exhaust. The sampling performance criteria for these situations may be the same as for normal final exhaust sampling; however, these conditions may be more extreme because higher concentrations, larger particle sizes, or because more reactive or corrosive gases may be expected.

5.5 Designing effluent discharge systems for sampler placement

Accommodating sampler placement is an effluent system design and construction requirement. Such design shall include provisions for extracting a representative sample and for supporting transport and collection equipment in a manner that ensures the extracted sample is transported and collected with minimal loss for all contaminants. The most important requirement for extracting a representative sample is that the sampling plane shall be located where the effluent is well mixed. Other considerations that should be included in the effluent discharge design are as follows:

a. Do not add another effluent discharge point to the stream beyond the sampling location;

b. Do not locate the sampling location upstream of any effluent attenuation devices;

c. Include a section upstream of the sampling plane where corrective devices such as mixing elements could be easily installed;

d. Locate the sampling plane downstream of devices that promote mixing of the contaminants;

e. Avoid the use of flow straighteners except after the contaminants are well mixed and only to remedy angular or cyclonic flow;

f. Locate the sampling plane close to the collector or analyzer to ensure that transport lines are short and have few bends and transitions;

g. Provide ample access to service and maintain the sampling system and to install any needed shielding;

h. Provide for a stable electrical supply, environmental conditioning, and low levels of vibration;

i. Provide ample access ports for visual inspection of the nozzle, flow transmitter verification, and sampler performance testing.

The conditions of the effluent stream may provide an indication that the stream is well mixed. Devices that will aid mixing include bends, a mixing plenum receiving one or more streams, baffles that promote mixing, or a turbulent stream in a long length of duct. Nevertheless, conditions within the devices or combination of devices may be such that streaming occurs or that separation is induced. Highly cyclonic flow can inertially separate large-sized particles (those with sizes on the order of several μm AD or larger), or a temperature gradient could cause condensation,

Stephan flow, or thermal density effects. Flaws in the emission control devices or physical or chemical conditions in the devices can induce streaming, which can lead to non-uniformities in concentration profiles.

6 Sampling system design

Regulations may require reporting emissions in either standard or actual velocities and densities whereas instruments are usually calibrated in either standard or actual. Care shall be taken when making measurements and preparing reports that one is aware of both the regulations and the quantity measured so that appropriate units are reflected. The following discussion cannot accommodate all possible situations and may be adjusted for particular situations where regulations or instrumentation differ.

A graded approach is recommended in the design of systems that fulfill the requirements for sampling radionuclides in stacks and ducts of the nuclear industry. If the source is Potential Impact Category (PIC) 3 of table 2, only periodic confirmatory sampling is required. Such sampling shall be carried out using either installed or portable equipment meeting or exceeding the requirements of this standard. Often extended sampling periods (on the order of several days) may be needed to adequately characterize a PIC 3 source. If the source is either a PIC 1 or a PIC 2 of table 2, continuous sampling is required; and, if the source is PIC 1, continuous monitoring is also required. The focus of this clause is on continuous sampling and monitoring requirements.

6.1 Sample flow rate

Selection of a sample flow rate is based on several factors. McFarland et al. (1998) provide an approach for selection of the flow rate through filter samplers used in the nuclear workplace, and that approach could serve as the basis for selecting the flow rate for effluent air sampling systems. By nature, selection of a flow rate will be a trade-off between the desired minimum detectable activity, analysis errors, and characteristics of available collectors or analyzers. In general terms, continuous extractive sampling systems for collection of particulate matter will typically operate at flow rates of 25 to 100 L min^{-1} while those for gases will operate in the range 0.1 to 100 L min^{-1}.

6.2 Bulk stream volumetric flow measurement

Accurate measurements of the flow in stacks and ducts must be provided because the accuracy of any emissions estimate is directly related to the accuracy of flow measurements. The flowrate of air exhausted through a stack or duct shall be periodically measured and may need to be continuously monitored if there is a potential for significant emissions.

6.2.1 Requirements

Flowrate of sources that are PIC 1 of table 2 shall be continuously measured, and sources that are PIC 2 shall be continuously measured if the flow rate is anticipated to vary by more than 20% during a year. If historical data are available, the 20% value can be approximated by the standard deviation of the measurements. If the variability of flow rate is based on engineering judgement, such factors as fan maintenance, the opening of doors, and the variations in the number of fans shall be taken into account in determining the need for continuously measuring flowrate. For effluents that fall into PIC 3 of table 2, only periodic measurements of flowrate may need to be performed.

If continuous measurement of flowrate is not required, annual measurements of flowrate shall be performed following the requirements of 40 CFR 60, Appendix A, Methods 1 and 2 subject to the modifications in annex A of this standard, or other methods that can be demonstrated to have equivalent or better accuracy. The modified Method 1/Method 2 will be denoted hereafter as the Reference Method.

For stacks and ducts that must be continuously monitored, the flow measurement and recording system shall be capable of determining the mass flowrate of the effluent stream with an accuracy that is within 10% of that measured with the

Reference Method. Here the mass flowrate is defined as the volumetric flowrate based on a pressure of 760 mm Hg (101.3 kPa) and a temperature of 25°C (298 K), and is given in units of m^3_{std}/s (or m^3_{std}/min). The use of these standard conditions is of value in dealing with sampling system data; however, in other topical areas of health physics such as dose assessment, the use of actual conditions may be more appropriate.

Any continuous flow measurement device shall be subjected to annual accuracy audits. Performance of the unit shall be compared against the Reference Method. If the sensor of the continuous flow measurement device is based on electronic or acoustical principles, automated daily checks of the instrument zero and span (or linearity) shall be made.

6.2.2 Apparatus and applications

Three types of systems are commonly used for continuously measuring flowrates in stacks and ducts: thermal anemometers, pitot tubes, and acoustic meters. Other methods may be used if their accuracy is within the limits specified in clause 6.2.1.

6.2.2.1 Thermal anemometers

The use of thermal anemometers is advantageous because they provide a readout that is independent of pressure and temperature and can be used directly to determine mass flowrate. Thermal anemometers should not be used if there is a possibility of condensed vapor being deposited on the sensing element. Also, if a background aerosol is present, the use of thermal anemometry is discouraged; however, a cleaning schedule may be set up if it can be demonstrated that the bias of results due to accumulation of debris on the nozzle will be less than 3% at the end of the interval of the cleaning schedule. Rakes (arrays of multiple sensors) of thermal anemometers are acceptable. However, the requirements of uniformity of velocity profiles stipulated in clause 4.2.2 accommodate the use of single point velocity determinations. When single point anemometry is used, a correction factor shall be established to relate average mass flowrate to the reading from the single thermal anemometer element. In many applications, it may be beneficial to deploy redundant (two) single-point thermal anemometry systems.

6.2.2.2 Pitot tubes

A pitot tube will provide a measurement of the velocity at a given point in the flow. Velocity, V (m/s), is calculated from

$$V = C_P \sqrt{\frac{2\,\Delta p}{\rho}} \qquad (2)$$

where: C_P is a pressure coefficient (dimensionless); Δp is the pressure difference between stagnation pressure and static pressure measured with the pitot tube (in units of Pa); and ρ is the air density (kg/m^3) in the stack or duct.

If a Prandtl-type pitot-static tube is used, the pressure coefficient is unity. However, if an S-type pitot tube is used, the pressure coefficient shall be validated using the procedure stipulated in the Reference Method.

The readings from a single point pitot tube can be correlated with the actual flowrate. Data from a single point pitot tube should be recorded at intervals not to exceed 10 min duration. For reporting purposes, the actual volumetric flowrate through the stack or duct, q_a (m^3/min), should be converted to standard conditions, q_{std}, from

$$q_{std} = q_a \frac{T_{std}}{T} \frac{p}{p_{std}} \qquad (3)$$

where: T_{std} is the standard temperature (298 K);

T is the temperature in the stack (K);

p is the absolute pressure in the stack (kPa);

p_{std} is the standard pressure (101.3 kPa).

If the absolute pressure in the stack does not vary by more than 5% during the course of a year (exclusive of variations in barometric pressure), and if the temperature in the stack does not vary by more than ±10°C during a year, average values of stack pressure and stack temperature may be used to calculate velocity. If the pressure and temperature variations are outside these ranges, pressure and temperature shall be continuously measured and a value of air density calculated and recorded at intervals that do not exceed 10 minutes. Velocity values shall be based on the calculated values of density.

A pitot tube should be inspected for the presence of deposits of contamination on an annual basis, or more frequently if the air is not HEPA-filtered. For some applications it may be necessary to perform daily instrument checks for assurance that there is no buildup of material on the ports of the pitot tube nozzle. Such checks may be performed by measurement of the pressure associated with a given rate of backflow through the ports. During the annual inspection, the system shall be checked for leaks. Leakage at average flow conditions shall not affect the results of differential pressure by more than 1%.

6.2.2.3 Acoustic flowmeters

These devices measure the time for acoustic signals to travel between two transceivers placed on opposite sides of a duct and displaced axially from one another. Acoustic velocity is independent of pressure but does depend on the square root of the absolute temperature in a stack. The acoustic flowmeter should accommodate measurements of temperature and take those values into account when calculating the velocity.

Velocity measured by this device is an average over a single line across the stack and not an area average, where the latter measurement would allow direct calculation of flowrate. Thus, a correction factor shall be established between the reading of the instrument and the volumetric flowrate through the stack. When such a correction factor is applied, the result will be the actual volumetric flowrate through the stack or duct, q_a. Through use of eqn (3), the flowrate can be converted to that at standard conditions, q_{std}.

If the absolute pressure in the stack does not vary by more than ±5% during the course of a year (exclusive of variations in barometric pressure), and if the temperature in the stack does not vary by more than ±10°C during a year, average values of absolute stack pressure and stack temperature may be used in eqn (3). If the pressure and temperature variations are outside these ranges, pressure and temperature shall be continuously measured. Values of flowrate at standard conditions will be calculated and recorded for intervals that do not exceed 10 minutes.

6.3 Nozzle design and operation for sampling aerosol particles

This method is applicable to sampling from stacks and ducts that have the potential to emit aerosol particles. This approach is based on experimental and theoretical evidence that extractive sampling from a single point in a qualified profile of duct flow where the flow is well mixed, with a properly designed nozzle, should provide a representative sample during normal conditions and an adequate sample during accident conditions.

6.3.1 Basic considerations

Inlet nozzles serve the function of removing a sample from the free stream of a stack or duct and rendering it compatible with transport to an analyzer or collector. Previously, the ANSI N13.1-1969 standard recommended nozzle designs for aerosol sampling. However, the use of nozzles that have constant internal cross sections and a 90° bend of the same cross section is no longer considered good practice due to substantial aerosol particle losses in both the straight entrance region and the bend, and due to errors associated

with off-design operational conditions (Fan et al. 1992; McFarland and Rodgers 1993). Also, ANSI N13.1-1969 recommended the deployment of multiple nozzles in circular ducts larger than 6-in. (152 mm) diameter or in rectangular ducts with cross-sectional areas greater than 0.5 ft^2 (0.046 m^2). For larger ducts, as many as 20 nozzles were recommended, with rakes (several nozzles on a common manifold) of such nozzles spanning the stack or duct. The use of these rakes is no longer considered good practice because for a given flowrate, smaller nozzle inlet diameters are used as the number of nozzles is increased to accommodate the ANSI N13.1-1969 recommendation of isokinetic (air velocity at the nozzle inlet plane matching that of the free stream air velocity) sampling. The use of large numbers of small nozzles exacerbates sampling deficiencies inherent in the ANSI N13.1-1969 nozzle design.

In place of multiple point sampling, single point representative sampling should be used, with the requirement that both fluid momentum and contaminant mass are well mixed at the sample extraction location in the sampling plane as specified in the performance criteria of clause 5.2.2.2. Also, the ANSI N13.1-1969 recommendation for isokinetic sampling is no longer required. Studies have shown that isokinetic operation is not a prerequisite for obtaining representative samples (McFarland and Rodgers 1993).

The design and use of an extractive aerosol sampling nozzle can have a significant impact on the quality of a sample. There are two basic factors by which a nozzle can produce a nonrepresentative sample: 1) operation in such a manner that the aspiration ratio, *A*, is not unity, and 2) losses on the internal walls of the nozzle, *Wl*. The two terms, aspiration efficiency and wall losses, are defined as

$$A_e = \frac{c_i}{c_\infty} \tag{4}$$

and

$$Wl = \frac{c_i - c_e}{c_i} \tag{5}$$

where: c_i is the concentration at the nozzle inlet plane;

c_∞ is the aerosol concentration in the free stream;

c_e is the concentration at the nozzle exit plane.

In evaluating the effectiveness of a sampling nozzle, both the aspiration ratio and wall losses should be considered. Their effects are manifested in the transmission ratio, *T,* which is the ratio of the aerosol concentration at the nozzle exit plane to the aerosol concentration in the free stream, as in

$$T_r = \frac{c_e}{c_\infty} \tag{6}$$

The transmission ratio, aspiration ratio, and wall losses are related by

$$T_r = A_e \left(1 \; Wl \right) \tag{7}$$

Although all three parameters are important, the performance of a nozzle is best described in terms of its transmission because that parameter provides a measure of the amount of aerosol that actually penetrates from the free stream to the exit plane of the nozzle.

6.3.2 Nozzle performance

A sampling nozzle shall have an aerosol transmission ratio within the range of 0.80 to 1.30 over the anticipated range of normal or anticipated accident operational conditions for an aerosol particle size of 10 μm AD, or for the range of sizes that could be encountered in normal operating or accident conditions if those sizes are greater than 10 μm AD. Also, the aspiration ratio of a sampling nozzle shall be within the range of 0.80 to 1.50 for the anticipated range of operating conditions and the previously noted particle size or sizes. Compliance shall be demonstrated with liquid aerosol particles, which will provide conservative transmission values in comparison with solid particles because liquid particles adhere to walls,

while solid particles may rebound or be re-entrained from a surface.

6.3.3 Nozzle designs

When a nozzle is operated isokinetically, the aspiration ratio is unity; however, the wall losses can cause the transmission to be considerably lower than unity. Fan et al. (1992) wind tunnel tested an elbowed nozzle with a nearly constant internal diameter designed in accordance with ANSI N13.1-1969. They found the wall loss ratio was approximately 75% for 10 μm AD aerosol particles at isokinetic conditions over a range of stack velocities. In addition, when a nozzle is operated at off-design conditions, the transmission ratio can be affected. These conditions can be produced by variations in the free stream velocity, by variations in sampling flowrate, and by a nonparallel orientation of the nozzle with the flow direction. The latter factor can be caused by nozzle misalignment or flow swirl. Performance of ANSI N13.1-1969 nozzles and the rakes of such nozzles are affected by all of these factors.

Modern nozzle designs have better performance characteristics than the original ANSI nozzles. As an example, McFarland et al. (1989) and Chandra and McFarland (1995) have developed shrouded nozzle designs that considerably reduce wall losses. Figure 2a shows a typical shrouded nozzle that was designed for use in stack sampling in the nuclear industry. The transmission of 10 μm AD aerosol through the nozzle as a function of free stream velocity is shown in figure 2b. In general terms, the wall losses for 10 μm AD aerosol particles are about one-fifth of those of the ANSI/HPS N13.1-1999 (1969) nozzles tested by Fan et al. (1992).

The shrouded nozzles are designed to be compatible with single-point sampling, where the sampler is operated at a constant flowrate with the flow velocity in the shroud being about 30% that of the nominal stack free stream velocity.

The transmission ratio for 10 μm AD aerosol particles is relatively unaffected by variations in stack velocity, flowrate, free stream turbulence and angle between the free stream and nozzle entrance. Williamson et al. (1987) and Chandra (1992) designed sharp-edged unshrouded nozzles that have wall losses of 10 μm AD particles that are approximately half of those of the ANSI N13.1-1969 nozzles.

The presence of a nozzle should not disturb the aerosol concentration in the stack or duct. Accordingly, the frontal area of a nozzle should not be greater than 15% of the stack or duct cross sectional area.

6.3.4 Application and performance considerations

The following factors should be considered in the selection and use of a sampling nozzle.

6.3.4.1 Location

Sampling should take place at a location where both the aerosol concentration and fluid momentum (velocity) are well mixed and thus meet the performance criteria of clause 5.2.2.2.

6.3.4.2 Orientation

For aerosol sampling, the nozzle axis should be aligned parallel to the temporal mean flow stream direction.

6.3.4.3 Transmission and aspiration ratios

The transmission and aspiration ratios of the selected nozzle design shall be traceable to experimental verification of performance for conditions that include the nominal sampling flowrate and range of anticipated sampling flow-rates, the nominal free stream velocity and the range of anticipated free stream velocities, and a particle size of 10 μm AD. If actual testing is used, the means for determining the transmission and wall loss ratios shall be documented. If reference to previous testing is employed, the equivalency of the selected design and the design that was tested shall be documented.

6.3.4.4 Sampling flowrate and free stream velocity

During operation of a nozzle, the sampling flowrate may be varied to accommodate changes in the free stream velocity, or it may be held constant to accommodate the requirements of the collector or analyzer. However, for record samples, if the source is PIC 1 of table 2, the sampling flowrate shall be varied in proportion to the flowrate through the stack or duct in order to permit an accurate assessment of the quantities of any releases. Continuous air monitors (CAMs) in PIC 1 applications may be operated at a fixed flowrate. If the sample flowrate is varied, the ratio of the sampling flowrate to the stack flowrate shall be established for nominal operational conditions of the stack or duct. Over the range of operational flowrates that is based on either historical records or *a priori* considerations, the ratio should not vary by more than ±25%.

6.3.4.5 Nozzle configuration

The leading edge of the nozzle should have a sharp edge with the external cone angle not to exceed 30°. Other configurations may be used if experimental data show either equivalent or superior performance to the sharp-edged nozzle. If the sampling nozzle is shrouded, the shroud should not have a sharp leading edge. For sharp-edged nozzles, the leading edge of the nozzle should be inspected for damage following installation and subsequent to any maintenance procedures in which the nozzle could be damaged.

6.3.4.6 Rakes

While the use of a sampling rake is discouraged, if one is to be used it shall be tested for aerosol transmission. Each of the nozzles shall meet the requirements contained in clause 6.3.2. Either *in situ* or laboratory tests may be used in the testing procedure to determine compliance. If all nozzles on the rake are identical and a nozzle can be separated from the rake, tests may be conducted on a single nozzle; otherwise, tests shall be conducted with the nozzles mounted on the rake and the rake shall meet the criteria in clause 6.3.2. Flowrate through each nozzle in a rake, or the velocity at the inlet plane of each nozzle in a rake, shall be measured by a method that does not affect the flow through other nozzles in the rake. Flowrate or inlet-plane velocity measurements may be conducted with the rake removed from the stack or duct. The flowrate or inlet-plane velocity of any nozzle may not differ from the mean flowrate by more than ±10%. In addition, the

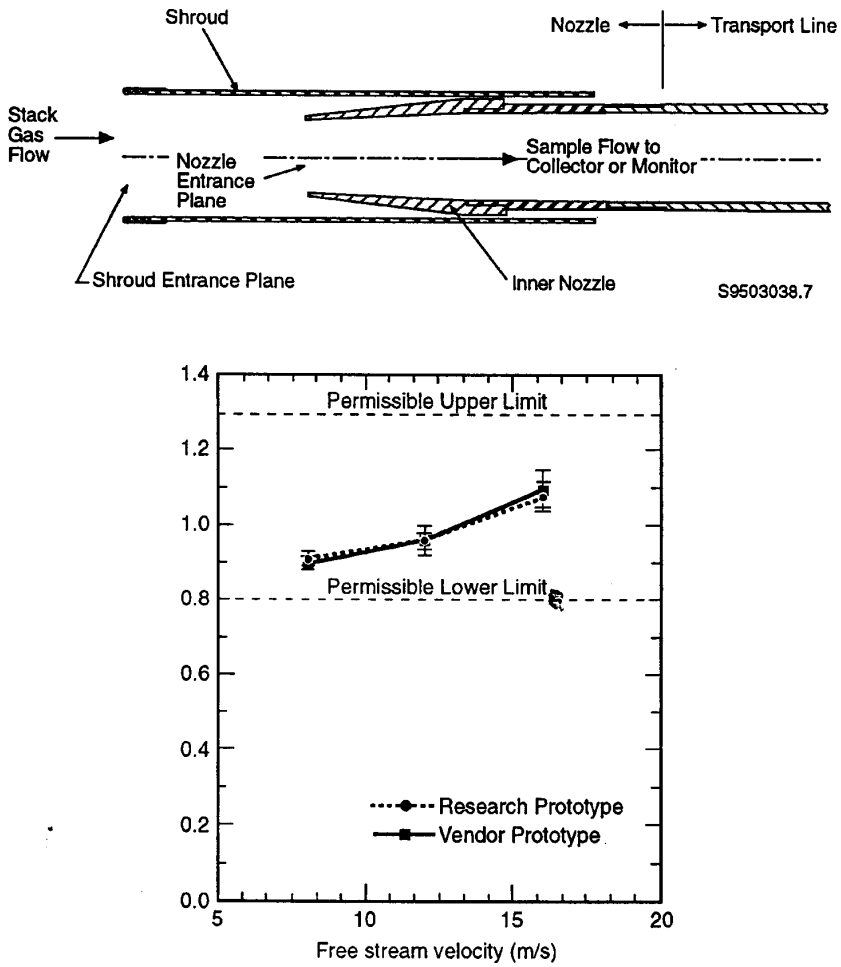

Figure 2 – Top: A shrouded nozzle designed for a sampling flowrate of 57 L min^{-1} (2 cfm). Bottom: Results of wind tunnel tests showing transmission of 10 μm AD aerosol particles through the nozzle shown in the top figure. Sample flowrate was maintained constant at 57 L min^{-1} during these tests.

transmission of an aerosol through a rake shall be measured or calculated and documented.

6.3.4.7 Materials of construction

Nozzles shall be constructed of materials that will not react with either the aerosol or the vaporous constituents of the gas stream. The average surface roughness of the internal regions of nozzle that contact the sampled stream should not exceed 0.8 μm. The average surface roughness of the external region of the sampling nozzle from the inlet plane to a distance of two nozzle inlet diameters from the inlet plane should not exceed 1.6 μm. A shroud should have an average surface roughness that does not exceed 3.2 μm.

6.3.4.8 Maintenance

The sampling nozzle shall be checked annually for alignment, presence of deposits of foreign materials, and other factors that could degrade the performance of the sampling system. If there are background aerosols that can produce deposits, a cleaning schedule should be established that will not allow over 5% of the inlet area of a nozzle to be occluded. For nozzles that are used to sample HEPA-filtered air, the nozzle should be cleaned if there are visible deposits of material on either the internal or external regions of the nozzle.

6.3.4.9 New concepts

When new approaches are developed for design and operation of nozzles, such designs may be used in ducts and stacks if it can be demonstrated experimentally that the designs meet, or exceed, the performance specifications given in clause 6.3.2. The test conditions should include experiments to determine the wall losses and aerosol transmission at conditions of 1) particle sizes of 3, 10, and 20 μm AD at the nominal free stream velocity and nominal flowrate; 2) maximum and minimum operational or anticipated free stream velocities for a particle size of 10 μm AD at the nominal sampling flowrate; and 3) maximum and minimum anticipated sampling flowrates for a particle size of 10 μm AD at the nominal free stream velocity.

6.4 Sample transport for particles

The transport of aerosol particles from a sampling nozzle to a collector or analyzer shall take place in such a manner that changes in concentration and size distribution of airborne radioactive materials are minimized within the constraints of current technology.

6.4.1 Depositional losses

The deposition of particles inside the transport tubing shall be evaluated either through experimental techniques, through use of documented computer codes (e.g., Riehl et al. 1996), or through use of documented and referenced hand calculations (Brockman 1993), for either 10 μm AD aerosol particles or the size range expected in the particular application under normal, off-normal, and anticipated accident conditions.

The straight sections of transport tubes, particularly horizontal tubing sections, should be kept as short as possible, and the number of bends should be minimized within the geometrical constraints of the application. There should be no inward facing steps at the tubing connections that cause more than a 1% reduction in tube diameter. The tubing ends shall be free of burrs and crimping. For record samples, it is recommended that not more than one 90° bend be used, although there may be applications where more than one bend may be necessary. Bends shall have a curvature ratio (radius of curvature of the bend divided by the tube diameter) of at least 3.0. Flattening of the bend caused by a bending process shall not exceed 15%, where flattening is defined in terms of the original and minor axes of the tube cross section at the angular midpoint of the bend. As an example, the diameters of a 90° bend would be measured at the 45° location. The ratio of the minimum tube diameter to the original tube diameter shall not be less than 0.85. The user should note that special fabrication techniques may be required to meet these specifications.

In general terms, there will be some losses of aerosol particles in transport lines, and any design will entail compromises. The design parameters shall be carefully chosen to optimize the utility of the overall system. The penetration of 10 μm AD aerosol particles from the free stream to the collector or analyzer should be known and should not be less than 50%. Annexes B and F provide guidance on assessing particle penetration.

6.4.2 Corrosion

The internal walls of the transport system shall be constructed of materials that are minimally reactive

to inadvertently deposited aerosol particles or to reactive vaporous compounds that could be present in the sample. The materials of construction for external walls and seals between sampling system components should also be compatible with the environment to which they are exposed. Materials recommended for the nuclear industry are stainless steel for general applications and tetrafluoroethylene for radioiodine.

6.4.3 Electrostatic effects and flexible tubes

If plastic is used in aerosol transport systems, internal electric fields can cause particle losses (Charuau 1982); in particular, plastic tubing that has been flexed can show abnormally high wall deposits (Liu et al. 1985). A transport system should be constructed of materials such as metals or conductive plastics that will not sustain internal electrostatic fields. In many applications it is useful or convenient to employ flexible nonmetallic tubing to connect a sampler or analyzer to a transport line, particularly if there is a need to isolate an analyzer from mechanical vibrations in the sample transport line. The inside diameter of the plastic line should not be smaller than the inside diameter of the components with which it is connected, and the bend curvature ratio should not be less than a ratio of three, nor may the curvature of a bend cause more than a 15% change in the inside diameter of the tube. If nonconductive flexible tubing is used, the line length exposed to the sample should not exceed two times the internal diameter of the tube.

Of the flexible tubes that can be categorized as nonconductors, neoprene and natural rubber are recommended to minimize electrostatic deposition of particulate matter (Charuau 1982). If radioiodine is present in the effluent stream, materials suggested in annex C should be used.

6.4.4 Smoothness of internal surfaces

To minimize aerosol depositional losses and to facilitate decontamination, the internal surfaces of transport lines should be as close to hydraulically smooth as practical. Drawn tubing or other types of tubes with ε/d_t less than approximately 5×10^{-5} are acceptable, where ε = height of surface roughness of the internal tube walls and d_t = tube diameter. This criterion requires an average surface roughness of approximately 1.6 μm or less for tube sizes that are on the order of 25 mm (1 inch) in diameter.

6.4.5 Condensation

Transport lines, collectors, and analyzers shall be designed to avoid condensation of vapors. Condensation takes place when the temperature of air in the transport line is less than the saturation temperature of the vapor of interest. Thermally insulating, and in some cases heating, the transport line may be required to prevent condensation. For situations in which heating of the sampling line may result in unacceptably high temperatures at a collector or analyzer, a dilution system should be considered; however, care should be exercised to ensure that the dilution process does not produce condensation at the mixing location. Experimental or numerical analyses shall be performed to demonstrate the effectiveness of any design provisions that are intended to minimize or preclude the formation of condensation in sample transport systems.

6.4.6 Cleaning transport lines

An additional consideration at some facilities is the need for cleaning transport lines. For applications in which the sampled air is HEPA-filtered, there may not be a need for cleaning within the expected lifetime of the installation; however, for applications where background aerosols are present, it may be necessary to periodically remove deposits from the internal walls of the transport system. As a minimum, for systems that sample HEPA-filtered air, inspections for deposits should be made annually. If there is an indication of deposits inside the nozzle inlet, the transport line shall be inspected; and, if deposits are visible inside the transport line, the line shall be cleaned. For systems that sample non-HEPA-filtered air containing background aerosols, if an estimate can be made of the rate of deposition of all aerosol particles on the internal walls of the system, the system should be cleaned when the mean mass of

deposited material exceeds 1 g/m^2. Alternatively, a cleaning schedule can be set up based on performance of the transport system. The interval between cleanings should not exceed that during which accumulations of wall losses will cause the overall penetration of 10 μm AD aerosol particles through the sampling system to be reduced by more than 10%. In addition, if there are indications of re-entrainment of deposits from the walls of the sampling system or if there has been sampling of easily re-entrainable aerosol particles (e.g., flakes), either of which could cause anomalous radiological data to be gathered, the system should be cleaned. Decontamination requirements shall be taken into account in any cleaning procedure.

6.5 Gas and vapor sample extraction and transport

Much of the above discussion applies generally for sampling particles and gases; however, consideration shall to be given to extracting and transporting vapors and gases to determine where special system design may be required. There are instances where gases may be monitored in the stack using an in-stack radiation detector. In these instances, sample extraction and transport are not considerations

When non-reactive gases and vapors are the only species being sampled, the sampling requirements are considerably simpler than those for aerosol particles. The requirements for minimizing particle line-loss are irrelevant. Deposition in long transport lines and condensation due to temperature changes in the line shall be avoided. If the flow can contain only gaseous contaminants, the nozzle design is not critical, but the sampling shall take place at a location where the flow is well mixed and meets the criteria of clause 5.2.2.2. The nozzle design can be simply an open ended or perforated tube. The extraction and transport requirements that apply include extracting the sample from a well-mixed location and avoiding water and vapor condensation in the transport and collection system (except where condensation is used as the collection method).

When non-reactive gases, vapors, and particles are being simultaneously sampled, the particle sample extraction and transport requirements shall apply, which will also ensure adequate delivery of the gas and vapor sample. The remaining consideration then is the selection of suitable collection devices. The gas or vapor collection device should be located downstream of a particle filter to eliminate potential radionuclide interferences by particulate matter.

When working with reactive gases and vapors, particular attention shall be paid to the sampling system construction materials and to the avoidance of condensation. The construction material should have minimum reactivity with the gas. Consideration shall be given to the advantages of providing a separate sampling system for the gases whenever the construction materials that would be desirable for the transport of the particle and gas samples are incompatible. In situations where even a low level of reactivity cannot be avoided, the transport line length shall be kept to a minimum. The penetration of the gas or vapor through the complete extraction and transport system shall be documented. The minimum transport efficiency for vapor or gas samples from the free stream to the collector/analyzer should be 50%. If long transport lines are unavoidable, consideration shall be given to the effect of transport and detection delay time caused by deposition, chemical transformation, and subsequent resuspension. Careful consideration should also be given to how significant an effect the delay has on the timeliness, interpretation, and usefulness of the resulting data. Although rapid changes in the emission may become smeared over a large time interval relative to the change in emission, the data may still be useful and quantitative when interpreted in that light. Annexes C and H provide guidance on the sampling of radioiodine and tritium and annex F provides guidance on verifying the transport of sampled constituents.

6.6 Collection of particle samples

6.6.1 General considerations

Depending on the purpose of the sample, a wide

range of techniques is available for monitoring or collecting airborne particles. Particles can be collected on filters for retrospective determination of total mass, radioactivity, or chemical form; in aerosol cyclones or cascade impactors for determination of particle size distribution; on electron microscope substrates for determination of particle morphology; or they can be observed by light-scattering or time-of-flight techniques for measuring number concentration and size. Near realtime devices such as alpha continuous air monitors (CAMs) typically collect particles on a filter or impaction substrate and monitor the accumulation of radioactivity with time. Critical issues for selection and operation of particle collection devices are:

a. appropriate presentation of the sample for realtime analyses or preservation of the sample for retrospective analyses;

b. adequate flowrates and detection efficiencies to meet sensitivity requirements;

c. minimal in-leakage within the collector;

d. minimal particle loss within the collection zone.

6.6.2 Filter media

Filters are porous structures with controlled external dimensions such as thickness and cross sectional area normal to the flow. Filtration is the most widely used technique for collection of aerosol particles because of its low cost and simplicity. Filters capture particles by a combination of physical processes, which include direct interception, inertial deposition, Brownian diffusion, electrical attraction, and gravitational sedimentation. As shown in figure 3, filters typically have a minimum collection efficiency for particles that are approximately 0.2 - 0.5 μm diameter Above about 0.3 μm diameter, filtration efficiency increases due to inertial impaction and below this size efficiency increases due to Brownian diffusion.

A common misconception is that filters act as sieves, and that there is a direct relationship between the pore size of a filter and the minimum particle size that can be collected. In reality, because collection occurs by a complex combination of mechanisms, filters with nominal pore sizes larger than 1 μm can be very efficient collectors of sub-micrometer particles. As demonstrated by Lindeken et al. (1964), membrane filters show no serious degradation of collection efficiency until the pore diameters exceed 5 μm. In fact, filters with a 5-μm pore size are often preferred because they have lower pressure drops than smaller pore-size filters, yet retain high efficiency values.

Many filter media are available for use in collection of aerosol particles (see, for example, Liu et al. [1983] and Lippman [1989]). Materials include cellulose, glass, quartz, and plastic fibers. Sintered structures of metals or mineral particles have been used for high temperature filtration. Users are cautioned to be selective in their choice of filter media. Selection should be based on careful consideration of collection efficiency for the typical particle size in the duct, the area of the filter, the pore size, the filter's resistance to air flow, the background radioactive material of the filter, filter fragility, cost, self-absorption within the filter, and chemical solubility. If the performance characteristics of the front and back surfaces of the filter are not within 5% of each other for the intended purpose of the sample, there shall be a readily accomplished means of identifying the appropriate surface for particle collection. The filter shall be strong enough to maintain integrity at the required sample flowrates and during handling activities. If a filter and sample are to be separated for a particular analytical method, the user should select a filter medium that can be easily dissolved by a method that will not attack the particles of interest. In other cases, it may be imperative that the sample be collected on the surface of the filter rather than imbedded in the filter. Higby (1984) has demonstrated that absorption of alpha radiation emitted from airborne particles collected on glass-fiber filters does not constitute a major source of error in estimating concentrations of airborne alpha-emitting

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

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

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

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

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

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

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

6.7 Collection of gas and vapor samples

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

6.7.1 Sampling with retention of specific constituents

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

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

6.7.2 Sampling without constituent separation

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

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

Volume collection methods include the following:

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

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

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

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

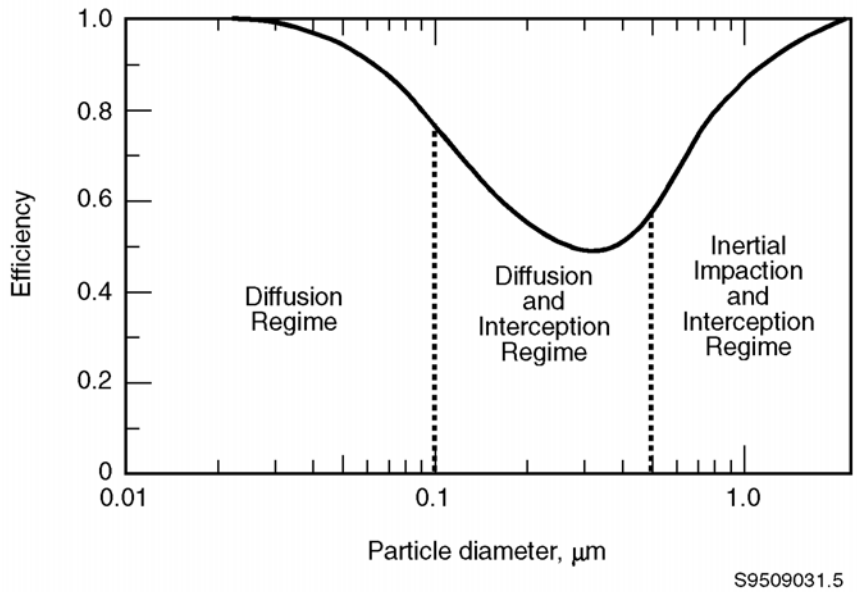

Figure 3 – Schematic of filter efficiency vs. particle size illustrating the different filtration regimes (Lee and Ramamurthi 1993)

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

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

6.8 Sample volume measurement

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

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

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

6.8.1 Basic considerations

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

6.8.2 Volume of air sampled

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

$$Q_T = \frac{q_1 + q_2}{2} \Theta \tag{8}$$

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

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

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

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

$$Q_T = \sum_{i=1}^{N} q_i \Delta t \tag{9}$$

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

6.8.3 Flowrate control

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

6.9 Leak checks

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

6.10 Optimization and upgrading of new and existing system

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

6.10.1 Defining the scope of the study

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

6.10.2 Identifying options and their consequences

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

6.10.3 Use of decision-aiding techniques

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

6.10.4 Upgrading and retrofit of existing stacks

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

7 Quality assurance and quality control

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

7.1 Quality assurance plan

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

a. organizational responsibilities;

b. personnel qualifications;

c. administrative controls;

d. means for identification of sources;

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

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

g. sample collection and tracking procedures;

h. calibration methods and calibration standards;

i. system operating procedures;

j. maintenance and inspection procedures;

k. procedure qualification;

l. data quality objectives and how they are accomplished;

m. audit and surveillance procedures;

n. corrective action program;

o. reporting and notification system;

p. program documentation requirements;

q. data analysis;

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

7.2 Documentation

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

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

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

7.3 System characterization and documentation

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

7.3.1 Source term

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

7.3.2 Effluent flow characterization

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

7.3.3 Design and construction

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

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

7.4 Training

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

7.5 Maintenance and inspection requirements

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

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

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

a. checks of nozzle position and orientation;

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

c. functional checks of instrumentation;

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

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

e. leak tests.

7.5.1 Sampling system flowmeter inspections

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

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

7.5.2 Continuous effluent flow measurement apparatus

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

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

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

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

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

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

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

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

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

7.6 Calibration

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

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

7.6.1 Calibration of sampling system flowmeters

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

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

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

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

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

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

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

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

F_k is a fluctuation constant. This is set at 1 for a meter whose readings do not fluctuate. If there are fluctuations, the parameter is set taken to be the average number of scale unit above and below the mean indicated value.

E_c is error (dimensionless) associated with determining the calibration factor, i.e., correcting the indicated flow. As an approximation, the error associated with the calibration instrument may be used.

E_t is error (dimensionless) associated with the measurement of the sampling time.

7.6.2 Calibration of effluent flow measurement devices

An effluent flow measurement system shall be calibrated at least annually against a reference method. The Reference Method for this standard is a modification of EPA Methods 1 and 2, which is discussed together with the requirements for the calibration in annex A. The goal of the calibration is to measure flowrate with an accuracy relative to the Reference Method that is within ±10%.

7.6.3 Calibration of timing devices

Timing devices should be calibrated at least annually. The maximum acceptable error is 10 minutes per month.

7.7 System performance criteria

Assuring satisfactory sampling system performance requires the implementation of carefully planned design, inspection, and maintenance procedures. Throughout this document, performance criteria for various elements have been included in the discussion of each element. For convenience, they are summarized in table 6. These criteria cover aspects of system design, operation, maintenance, and calibration.

7.8 Technical guidance

QA programs are typically prepared in response to specific guidance documents. QA guidance may be obtained from documents such as 40 CFR 61, EPA/600/4-77/027b, 1988; EPA/520/1-80-012, 1980; U.S. DOE Order 5700.6C, Order 5400.2A, Order 5484.1, Order 5480.4, Order 5400.5; U.S. NRC Regulatory Guide 4.15; ASME NQA-1, 1990; and Methods of Air Sampling and Analysis, General Techniques, Part 26.

Table 6 –Summary of performance criteria. Table is based on presence of aerosol particles in the stack or duct. If no particles can be emitted, criteria are to be based on gas characteristics only.

Performance criterion	Reference
Total transport of 10 μm AD particles[1)] and vaporous contaminants shall be >50% from the free stream to the collector/analyzer.	Clauses 6.4.1 and 6.5
Sampler nozzle inlet shall have a transmission ratio between 80% and 130% for 10 μm AD particles[1)].	Clause 6.3.2
Sampler nozzle shall have an aspiration ratio that does not exceed 150% for 10 μm AD particles[1)].	Clause 6.3.2
Characteristics of a suitable sampling location are: a) coefficients of variation over the central 2/3 area of the cross section within ±20% for 10 μm AD particles, gaseous tracer, and gas velocity. b) flow angle <20° relative to the long axis of the stack and nozzle inlet. c) the tracer gas concentration shall not vary from the mean >30% at any point on a 40 CFR 60 Appendix A Method 1 velocity mapping grid.	Clause 5.2.2.2
Effluent flowrate continuous measurement required if flow variation is >±20% in a year.	Clause 6.2.1
Effluent and sample flowrate shall be measured within ±10%.	Clauses 6.2.1 and 7.6.1
Continuous sample flowrate measurement and control required if flow varies >±20% during a sample interval. Flow control shall be within ±15%.	Clauses 6.8.2 and 6.8.3
PIC 1: Continuous measurement of effluent flowrate and continuous measurement and control of sampling flowrate (to track flowrate in stack or duct within ±20% of a predetermined value).	Clauses 6.2.1, 6.8.1, and 6.8.3
PIC 2: Continuous flowrate measurement unless flowrate variation is less than ±20% during a year	Clause 6.2.1
Periodic inspections of nozzles, transport lines, sample, and effluent flowmeters shall be conducted	Clause 7.5
Periodic calibrations of effluent and sample flowmeters, CAMs, and sample analysis instrumentation shall be conducted.	Clause 7.6

[1)] The criterion particle size may be larger as stated in the referenced clauses.

Annex A
(informative)

Techniques for measurement of flowrate through a stack or duct

A.1 Introduction

The volumetric flowrate, *q*, through a stack or duct is defined as:

$$q = \int_{\text{Area}} \mathrm{V}\,\mathrm{dA} \tag{A-1}$$

where: *V* is the velocity at any location across a stack or duct; *A* is the cross sectional area of the duct.

ANSI and the American Society of Mechanical Engineers (ANSI/ASME PTC-38, 1980) standardized a method for determining *q*, which involved measuring the velocity at a finite number of points in a duct, where each point was chosen as the center of an area element. They utilized the relationship:

$$q = \sum_{\mathrm{i}=1}^{\mathrm{N}} \mathrm{V_i}\,\Delta\,\mathrm{A_i} \tag{A-2}$$

where: V_i is the velocity at the midpoint of the *i*th element; ΔA_i is the area of the *i*th element.

The cross section of the stack or duct is divided into *N* elements. In usual practice, all of the *N* elements have equal areas. The ANSI/ASME approach was embodied in EPA Methods 1 and 2 (40 CFR 60, Appendix A), which serves as the Reference Method for this ANSI Standard (clause 6.2.1). The requirements for absence of cyclonic flow given in Methods 1 and 2 are also included in the Reference Method.

The flowrate *q* is associated with the air density, ρ, that exists in the stack or duct. Density, is calculated from the ideal gas equation for dry air, viz:

$$\rho = \frac{p}{RT} \tag{A-3}$$

where: *p* is the absolute pressure in the stack or duct (kPa); *T* is the absolute temperature (K); *R* is the gas constant for air (0.287 kJ/kg · K).

The flowrate at standard conditions, q_{std}, is the parameter that is to be calculated for reporting and analysis purposes, and it is related to the actual flowrate, *q*, by:

$$\rho\, q = \rho_{std}\, q_{std} \tag{A-4}$$

where: ρ_{std} is the density of air based on standard temperature and pressure (101.3 kPa and 298 K).

The flowrate at standard conditions can then be expressed from eqn (A-4) as:

$$q_{std} = q \frac{T_{std}}{T} \frac{p}{p_{std}} \tag{A-5}$$

In practice, q is determined from velocity measurements at traverse points specified in EPA Method 2, with the value calculated from eqn (A-2). The temperature and pressure in the stack or duct are measured in accordance with the requirements of EPA Method 2.

A.2 Special considerations for use of EPA methods 1 and 2 in sampling stacks and ducts of the nuclear industry

The Reference Method for determining air flowrate through a stack or duct, modified EPA Methods 1 and 2 (40 CFR 60, Appendix A), was developed for flowrate determinations in nonnuclear stacks and ducts. There are several differences with typical sampling in nuclear stacks and ducts that need to be taken into consideration.

A.2.1 Pitot tubes

An S-type pitot tube is recommended under EPA Method 1, for the purpose of reducing the risk of dust plugging the ports of the pitot tube when measurements are made in dusty environments. Dust loading during velocity mapping in a stack or duct in the nuclear industry is not usually a concern, thus Prandtl-type pitotstatic tubes should be considered as the reference apparatus for sampling under the requirements of the present standard. If there are situations where dust loading may be of concern, an S-type pitot tube should be considered.

A.2.2 Mean molar mass of the stack gas

Often in the industrial applications for which EPA Methods 1 and 2 were designed, the gas being tested contains products of combustion or elevated water vapor resulting from drying operations. In contrast, the gas in most stacks and ducts of the nuclear industry is ventilation air. It is unnecessary to determine the mean molar mass, M (called the molecular weight in EPA Method 2), for most stacks and ducts. However, if it can be anticipated that there will be more than 10% water vapor in the stack or duct, or if there are other gases that will change the mean molar mass by more than 4% from the value for dry air (28.96 kg/kmol), a determination is made of the mean molar mass of the gas following the method recommendations given in EPA Method 2 (Section 2.6). If it is necessary to measure the mean molar mass, the resulting value is used to calculate the gas constant in equation (A.4) as:

$$R = \frac{R_u}{M} \tag{A-6}$$

where: R_u is the universal gas constant (8.314 kg/kmol K).

A.2.3 Thermal anemometers

If the mean molar mass and water content of the stack gas are in accordance with the values stated, the gas can be treated as air; if the dust loading in the stack or duct is such that any deposits on a thermal anemometer probe will not change the calibration of a thermal anemometer by more than 3% during the course of the velocity measurements; and, if there is no condensation of water vapor or other vapors on the sensor during flow measurements, a thermal anemometer can be used in this ANSI standard in lieu of a pitot tube.

When a thermal anemometer is used for velocity mapping in a stack or duct, the flowrate based on standard conditions, q_{std}, is determined from:

$$q_{std} = \sum_{i=1}^{n} V_{std,i} \, \Delta A_i \qquad \text{(A-7)}$$

where: $V_{std,i}$ is the equivalent velocity at standard conditions measured with a properly calibrated thermal anemometer at the center of the *i*th element of area.

A.3 Conversion of data from single point or single line measurements to total flowrate

If continuous single point velocity measurements from a pitot tube or a thermal anemometer, or line integral measurements from an acoustic flow meter are used to infer the total flowrate through a stack as a function of time, the resulting data must include a correction factor account for the shape of the velocity profile. The correction factor is determined by comparing flowrate determinations from use of the single point technique with those of the Reference Method for this standard (EPA Methods 1 and 2).

A.3.1 Pitot tube

The velocity-averaging correction factor for a pitot tube, C_{pt}, is defined as:

$$C_{pt} = \frac{V\,A}{q} \qquad \text{(A-8)}$$

where: V is the velocity measured by a pitot tube at the single point where monitoring will be carried out; A is the cross sectional area of the duct; q is the flowrate through the stack or duct as determined from use of the Reference Method and as calculated from eqn (A-2).

Usually, the single point would be located near the center of the duct. Multiple points could be used, in which case the value of V is the average of the values from the multiple points.

The velocity, V, will be continuously monitored during the period that the Reference Method testing is performed to established the velocity-averaging correction factor, C_{pt}. If the value of V changes by more than 5% during the course of testing, the data should be rejected and the test repeated. If the stack is subject to long-term flowrate variations that exceed 25%, additional tests should be carried out at the highest flowrate (if it exceeds the base condition by more than 25%) and the lowest operational flowrate (if it deviates from the base condition by more than 25%) to establish values of the velocity-averaging correction factor at those conditions. A single value of the flow correction factor may be used if the range of flow correction factor values is within 7% of the base condition. If the values of the correction factor at the extreme flow conditions are greater than 7% of the base condition, then a relationship must be established between the velocity correction factor and flowrate.

At least two replicate tests should be employed to establish a value of the correction factor. During routine use, the flowrate is determined from readings of the single point pitot tube using:

$$q = C_{pt} V A \tag{A-9}$$

A.3.2 Thermal anemometer

A thermal anemometer located at a single point in a flow field will provide a reading that is related to the total flowrate at standard conditions through the relationship:

$$q_{std} = C_{ta} V_{std} A \tag{A-10}$$

The value of the velocity-averaging correction factor, C_{ta}, is determined by comparing the readings of a thermal anemometer operated at a single point with simultaneous data from a Reference Method flowrate test. The data from the Reference Method test must be corrected to standard conditions through use of eqn (A-5). Requirements for carrying out tests are the same as those for the pitot tube correction factor, clause A.3.1.

Continuous measurements of the effluent flowrate at standard conditions can be obtained by using a rake of thermal anemometers, with the individual anemometer elements placed on an EPA Method 1 grid. Provided the electronic signals are processed properly, the output reading of such a system will be the flowrate according to eqn (A-6).

A.3.3 Acoustic flow meter

The reading provided by an acoustic flow meter is a distance-weighted average velocity across a line between a sending transducer and a receiving transducer. As such, the velocity reading is not directly related to flowrate even along the line because flowrate must be based on an area-weighted average velocity. To obtain the flowrate through a stack or duct from acoustic flow meter readings also requires development of a velocity-averaging correction factor, C_{af}, which will give:

$$q = C_{af} V A \tag{A-11}$$

where: V is the line average velocity obtained from the acoustic flow meter.

The approach and requirements for determining C_{af} are the same as those for the single point pitot tube.

Annex B
(informative)

Modeling of particle losses in transport systems

Aerosol particles can be deposited on internal surfaces of transport systems as a result of the actions of mechanisms that cause particles to move transverse to air flow streamlines. Included are such phenomena as gravitational settling, inertial impaction, turbulent inertial deposition, and Brownian diffusion. For most transport systems, the Brownian diffusion mechanism is of significance only for aerosol particles with sizes smaller than approximately 0.3 m; whereas, the other mechanisms are of importance for particles larger than this size. Turbulent deposition is of consequence for flows with Reynolds numbers >2200, where the Reynolds number (Re) is given by:

$$Re = \frac{\rho\, U_m\, d_t}{\mu} \tag{B-1}$$

where: ρ is gas density (kg/m^3); U_m is mean (spatial) velocity at a cross section of the transport system (m/s);
d_t is tube diameter (m); μ s air dynamic viscosity (Pa • s).

For a tube of circular cross section, the Reynolds number can also be expressed as:

$$Re = \frac{4\, \rho\, q}{\pi\, d_t\, \mu} \tag{B-2}$$

where: q is volumetric flowrate through the tube (m^3/s) and is equal to the product of the mean velocity and the cross sectional area.

The combination of flowrate and tube diameter of most aerosol sampling systems is such that the flow is turbulent.

Empirical or semi-empirical models for predicting the effects of the various depositional mechanisms exist for most components of a sampling system. For nozzles, the losses are controlled by inertial forces including those associated with flow turbulence, the Saffman force and, occasionally by gravitational settling; for vertical tubes, the depositional losses are assumed to be controlled by turbulent inertial deposition and Brownian diffusion; for horizontal tubes, the losses are caused by gravitational settling, turbulent inertial deposition and Brownian diffusion; and, for bends, the losses are controlled through the effects of inertial impaction. The data bases used for generating the models typically assume the velocity and concentration profiles are uniform at the entrance section of the component of interest. It is to be expected that this assumption would not be fulfilled in many sampling systems because the flow disturbance created by an upstream component could affect the depositional characteristics of a succeeding component; however, in experimental studies with a composite transport system (nozzle, horizontal tube, inclined tube, vertical tube and bends) McFarland et al. (1991) and Wong et al. (1996) showed that the use of a model that was based on a sequential combination of components with assumed undisturbed inlet conditions, compared well with experimental data.

B.1 Aerosol penetration through transport system components

The penetration, P_j, of aerosol through the *j*th component of a transport system is defined as:

$$P_j = \frac{c_{e,j}}{c_{i,j}} \tag{B-3}$$

where: $c_{e,j}$ is aerosol concentration at the exit plane of a component; and $c_{i,j}$ is aerosol concentration at the inlet plane of a component.

If there are *n* components in a sampling system, it is assumed the overall penetration, *P*, can be calculated as though each component were independent, which gives:

$$P = \prod_{j=1}^{n} P_j \tag{B-4}$$

Estimates of particle losses in sampling systems can be performed with the aid of available software (Riehl et al. 1996) or by hand calculations (Brockman 1993). As an example, the U.S. Nuclear Regulatory Commission has made available PC-based software, DEPOSITION, for calculating the losses of aerosol particles in transport systems (Riehl et al. 1996). It includes models for losses in certain types of nozzles, straight tubes, bends, and fittings that serve as transitions in tube diameter, either to enlarge or reduce the diameter. Losses associated with contractions in fittings are discussed in Muyshondt et al. (1996).

B.1.1 Wall losses in nozzles

At the present time there is no general model for predicting wall losses in nozzles. Fan et al. (1992) made an experimental correlation of wall losses as a function of design and operational conditions for isokinetic nozzles of a Willeke-Okazaki configuration (1987), where those nozzles are similar to the ANSI N13.1-1969 design but with the exception there is no bend. The model of Fan et al. (1992) is based on experiments, which encompassed sizes of 10 and 20 μm, so it cannot be used as a general predictive tool for all nozzle applications; nevertheless, it does provide the basis for estimating internal wall losses in the straight region of ANSI N13.1-1969 nozzles upstream of the bends.

The code, DEPOSITION 4.0, includes the Fan et al. (1992) model for use with unshrouded isokinetic nozzles. It may overestimate the losses in more modern designs of isokinetic nozzles such as is illustrated in figure B.1 (Chandra 1992). A shrouded nozzle (McFarland et al. 1989) is basically a nozzle fitted with a flow decelerator (see figure 2 of this standard). It has lower wall losses than an unshrouded nozzle and it is less susceptible to off-design sampling conditions (e.g., off-angle flow direction, changes in sampling flowrate or changes in free stream velocity) than an unshrouded nozzle (Chandra and McFarland 1995). If the DEPOSITION model is applied to a system fitted with a shrouded nozzle, the code calculates aerosol transmission based on the model of Gong et al. (1996).

B.1.2 Straight tubes

The penetration of particles through a straight tube is calculated from:

$$P = \exp\left(-\frac{\pi\, d_t\, v_e\, L}{q}\right) \tag{B-5}$$

where: v_e is effective depositional velocity; and *L* is length of the straight section of tubing.

The effective depositional velocity is the vector sum of the gravitational settling terminal velocity (which is always directed downward), and the turbulent inertial deposition and Brownian diffusion velocities which are directed radially outward in a tube. A basic assumption when using this model is that aerosol particles are well mixed across any cross section of a tube.

The effective deposition velocity for an inclined tube, figure B.2, was modeled by Anand et al. (1992) as:

$$v_e = \frac{1}{2\pi} \int_0^{2\pi} (\mathrm{v_d} \;\; \mathrm{v_{ge}} \sin\alpha)\, \mathrm{d}\alpha \qquad \text{(B-6)}$$

where: α is angular coordinate of a tube cross section (figure B.4); v_d is depositional velocity due to the combined effects of thermal (Brownian) diffusion and turbulent inertial deposition; and v_{ge} is cross-stream component of gravitational settling velocity.

For a tube that is inclined at an angle of ϕ relative to the vertical direction:

$$v_{ge} = v_g \sin\phi \qquad \text{(B-7)}$$

where: v_g is the sedimentation velocity. Eqn (B-6) is subject to a constraint, namely:

$$(v_d - v_{ge} \sin\alpha) > 0 \qquad \text{(B-8)}$$

If the constraint is not satisfied:

$$v_e = 0 \qquad \text{(B-9)}$$

The constraint is necessary because otherwise the prediction would be equivalent to aerosol particles being transported from the environment through the top (relative to the earth's surface) of a tube.

If the effects of both gravitational settling velocity in the cross stream direction and the turbulent inertial deposition velocity are of consequence, there will be a tube diameter that optimizes aerosol penetration because for a fixed flowrate, tube sizes smaller than the optimal value will have increased turbulent depositional losses and tube sizes larger than the optimum will have enhanced gravitational depositional losses.

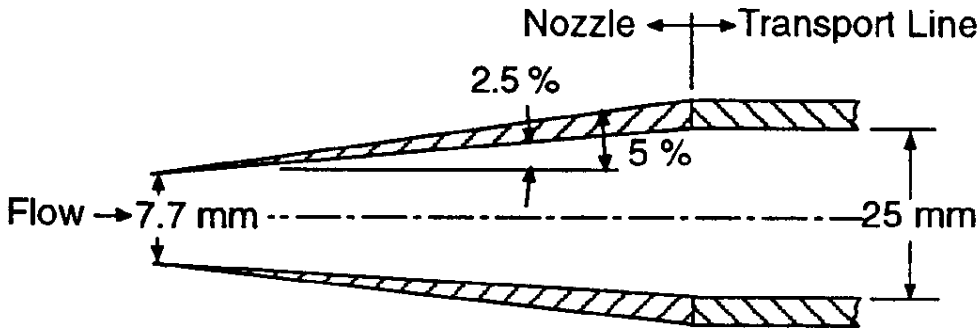

Figure B.1 – Unshrouded nozzle of Chandra (1992), which has about ½ the wall losses of 10 μm AD aerosol particles of a nozzle with constant internal diameter

A dimensionless particle deposition velocity in tubes can be correlated with a dimensionless particle relaxation time. Several semi-analytical models that lead to this correlation have been proposed; however, at this time, none can predict deposition of particles in the inertial size regime (>1 μm AD) from basic principles. Onda (1977) reviewed the various models and compared them with experimental data and concluded the model of Beal (1970) provided the best fit. The present version of DEPOSITION uses this model to predict the deposition. However, pure curve fitting of experimental data could also be used to provide estimates of the depositional velocities. The latter approach was used by Agarwal (1975), but his model does not take into account deposition due to the Brownian diffusion mechanism.

Particle deposition in fully developed laminar flow can be modeled with the theory of Thomas (1958) for gravitational settling and Gormley and Kennedy (1949) for Brownian diffusion. However, true laminar flow does not often occur in straight tubes because straight tubing sections are usually proceeded by disturbances such as bends. Typical sample transport tubes have Reynolds numbers that are >1000, which can cause the effects of any upstream flow disturbances to effect flow mixing downstream from the disturbance and thus would render a well-mixed deposition model such as eqn (B-5) more relevant than a laminar model with no bulk fluid mixing. For this reason, a well-mixed submodel, such as that utilized in DEPOSITION, can be employed for straight tubes when the Reynolds number is greater than 1000. For bends, a distinction is made between laminar and turbulent flows.

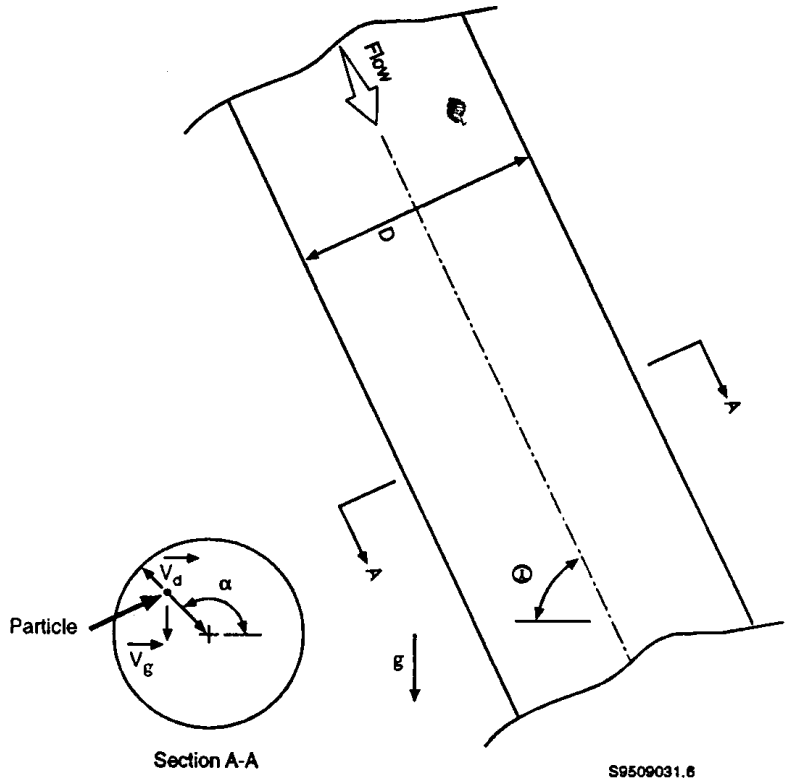

Figure B.2 –Geometric model to illustrate parameters used to model aerosol deposition in a straight tube

B.1.3 Bends

Particle losses in bends are principally due to the effects of particle inertiathe air flow follows a curved path and the particles tend to go straight. Neglecting Brownian diffusion, turbulent inertial deposition, and gravitational effects, analyses show that for two-dimensional channels, the penetration is a function of the Stokes number, Stk, where:

$$\mathrm{Stk} = \frac{C\,\rho_w\,D_a^2\,U_m}{9\,\mu\,d_t} \qquad \text{(B-10)}$$

where: *C* is Cunningham's slip correction (Fuchs 1964); ρ_w is density of water; and D_a is aerodynamic particle diameter.

The analysis for particle deposition in bends of circular cross section is complicated by the fact the flow is three dimensional. A secondary flow is established as the air passes through the bend, where the secondary flow consists of a set of counter-rotating vortices in which air goes from the inside of the bend to the outside of the bend along the tube diameter, and goes in the reverse direction along the tube circumference. In this

case, the particle deposition is a function of not only the Stokes number, but also the curvature ratio, R_o, and the Dean number, *De*, where:

$$R_o = \frac{R_c}{d_t} \tag{B-11}$$

and

$$De = \frac{Re}{\sqrt{R_o}} \tag{B-12}$$

where: R_c is the radius of the tube bend.

Pui et al. (1987) noted that for turbulent flow, when the curvature of the bend is such that $2.5 \leq R_o \leq 15$, the radius of curvature has little effect on particle trajectories and the deposition will depend, at most, on *Stk* and *Re*. Experimental data for the 90° bends with turbulent flow Reynolds numbers of 6,000 and 10,000 showed that the penetration could be correlated with only the Stokes number, namely:

$$P = 10^{-0.963Stk} \tag{B-13}$$

It should be assumed that the uncertainty in this model will increase for Reynolds numbers outside of the test range. For laminar flow, Tsai and Pui (1990) numerically modeled particle deposition in 90° bends and their results include the effects of secondary flow. They carried out calculations over a range of curvature ratios and Dean numbers and provided empirical correlations of the results, which showed the efficiency depends upon the Stokes number, curvature ratio, and the Dean number.

In the software DEPOSITION, the model of Tsai and Pui (1990) is used for Reynolds numbers <1100, and the model of Pui et al. is used for Reynolds numbers ≥1100.

B.2 Sample calculation of losses in a transport system

As an illustration of the calculation of particle losses in a transport system, assume the geometrical configuration shown in figure B.3 for a system that is designed to sample 10 μm AD aerosol particles at a flowrate of 56.6 liter/min (2 cfm) from a free stream that has a velocity of 10 m/s. Further assume the sampled air is at a temperature of 25°C and a pressure of 760 mm Hg. Suppose a shrouded nozzle is used to extract the sample, and the shroud has an internal diameter of 52.8 mm and the internal nozzle has a diameter of 18.2 mm at the inlet plane. Assume the velocity reduction ratio of the shrouded nozzle (free stream velocity divided by the velocity in the shroud) is 3.31. Also, assume the sampling tube has a 28.6 mm inside diameter (1-1/4-inch outside diameter with a 0.065-inch thick wall). The input and output values for the DEPOSITION 4.0 code are shown in table B.1. The overall penetration through the system is 77.3%, with the losses being dominated by the 1-m-long horizontal tube and the bends.

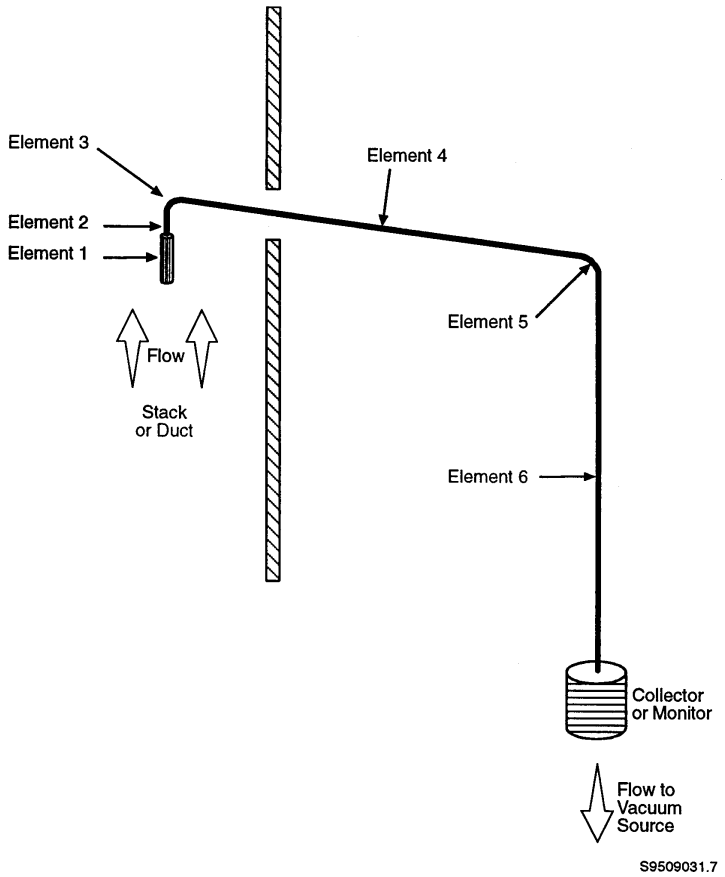

Figure B.3 - Layout of example aerosol transport system. Free stream velocity = 10 m/s and is reduced to 3.0 m/s in the shroud. Tube diameter is 28.6 mm.

Table B.1 – Example of using a computer code (DEPOSITION 4.0) to predict aerosol penetration through a transport system (figure B.3). Tube diameter is 28.6 mm, free stream velocity is 10 m/s with a shroud reducing that to 3.0 m/s at the inner nozzle inlet, and the particle size is 10 μm AD.

Input parameters	Output values
1) Flowrate: 56.6 liter/min	1) Penetration (transmission) through nozzle (Element 1): 97.4%
2) Tube diameter: 28.6 mm	2) Penetration through Element 2: 100.0%
3) Number of components: 6 (including a shrouded nozzle which is the first element)	3) Penetration through Element 3: 93.3%
4) Particle density: 1 g/cm^3	4) Penetration through Element 4: 91.3%
5) Particle size: 10 μm AD, monodisperse	5) Penetration through Element 5: 93.3%
6) Flowrate: 56.6 liter/min	6) Penetration through Element 6: 99.9%
7) Free stream velocity: 10 m/s	7) OVERALL PENETRATION: 77.3%
8) Element 1: Shrouded probe: a. inner probe diameter = 18.2 mm b. shroud diameter = 52.5 mm c. shroud velocity reduction ratio = 3.31 d. probe angle with free stream = 0°	
9) Element 2: Tube, 0.2 m long, 0° from horizontal	
10) Element 3: Bend, 90°	
11) Element 4: Tube, 1 m long, 0° from horizontal	
12) Element 5: Bend, 90°	
13) Element 6, Tube, 2 m long, 90° from horizontal	

Annex C

(informative)

Special considerations for the extraction, transport, and sampling of radioiodine

C.1 General considerations

Obtaining samples of airborne radioiodine is complicated because it is present in air effluents in several forms, viz: particulate matter, elemental iodine (I_2), hypoiodous acid (HOI), and in organic form, principally methyl iodide (CH_3I). The existence of the HOI form is not universally accepted, but it is postulated to be that otherwise indeterminate form with a deposition velocity lower than that of elemental iodine and that it will penetrate a cadmium iodide bed but it will be collected by an iodophenol bed in a species sampler.

These chemical forms of radioiodine, particularly the elemental form, may be expected to initially deposit in ducts and in sampling lines and then subsequently be resuspended and emitted as the same or another form (Cline 1991). The organic form is the least depositing and only a small fraction of it is collected by some of the solid adsorbents that are used to limit radioiodine emissions (Kovach 1980). However, it cannot be ruled out that during off-normal events the major form of radioiodine will be elemental. Therefore, evaluations of sample transmission under off-normal conditions should assume that form. Glissmeyer and Sehmel (1991) summarized the more recent studies on radioiodine sampling and transport, and many of the following considerations are based on that summary.

C.2 Extraction and transport

The considerations for the extraction of gases and vapors set forth in clause 4.3 of this standard are applicable to radioiodine. In view of the likelihood that at least some of the radioiodine in an air effluent will be attached to particulates, all of the considerations applicable to them as set forth in the main body of this standard and its annexes also apply to the extraction and transport of radioiodine.

Laboratory studies have shown that in the extraction and transport of radioiodine, materials that contact the radionuclide may interact with it (e.g., copper, PVC, Buna-N). These materials should be avoided. Studies by Kabat (1983) indicate that the preferred materials are Teflon, polyethylene, aluminum, carbon steel, and stainless steel.

Condensation of the iodine and water vapor in transport lines should be avoided by heat tracing the lines to at least 50°C (~120°F) and by avoiding abrupt temperature transitions.

The following equation (Glissmeyer and Sehmel 1991) relates the penetration at equilibrium, P, of radioiodine in transport lines to the so-called deposition velocity and parameters of the sampling system:

$$P = e^{-4\frac{v_d}{U_m}\frac{L}{d_t}} \qquad \text{(C-1)}$$

where: P is c_e/c_i; c_e is outlet concentration; c_i is inlet concentration; v_d is dry deposition velocity; U_m is average air velocity in transport line; L is length of transport line; and d_t is diameter of transport line.

From this equation it is evident that the penetration of radioiodine vapor will be optimized by minimizing the length of the transport line and using the largest diameter and the highest flow velocity subject to external constraints (e.g., particle transport, space availability, or collector capacity).

Eqn (C-1) does not take radioactive decay or resuspension into account. A model by Unrein et al. (1985) gives an equilibrium relationship that includes these effects; namely:

$$P = \frac{1}{1 + V_d \left(\frac{\pi\, d_t\, L}{q}\right)\left(\frac{\lambda}{\lambda + r}\right)} \qquad \text{(C-2)}$$

where: r is resuspension rate, time^{-1}; and λ is decay constant, time^{-1}.

Eqn (C-2) suggests that the greater the resuspension rate, the larger the penetration. This is also illustrated in figure C.1 where penetration is shown as a function of time and resuspension rate. However, Glissmeyer and Sehmel (1991) indicate that resuspension rates of deposited radioiodine, for each radioiodine species, decrease as a function of time. Resuspension rates are also dependent on the amount of iodine initially deposited, of which some seems to remain firmly deposited. The latter has not been directly observed by laboratory studies, but can be estimated on the basis of an activity balance following prolonged observation. Finally, Glissmeyer and Sehmel (1991) state there are no satisfactory experimental verifications of predicted penetration factors under either equilibrium or transient conditions. However, the following generalizations can be made from the limited available data, principally that of Unrein et al. (1985).

In a summary of sampling systems for reactors, Glissmeyer and Sehmel (1991) indicate that a typical sampling system consists of a 15-mm-diameter (5/8 in.) stainless steel transport line that is about 52 m (170 ft) in length with a flowrate of about 57 liter/min (2 cfm). Simulated sample transport lines with a range of similar designs were tested by Unrein et al. (1985) who measured short-term (on the order of two hours) penetration factors of 0.62 for injected ^{131}I (as I_2) through 19 mm (3/4 in.) diameter by 48 m (140 ft) long tubes. Glissmeyer and Sehmel (1991) predicted the equilibrium penetration factor to be about 0.75, with an approximate time of two weeks to reach equilibrium.

With the caveat that the penetration factor was not measured in the Unrein et al. (1985) tests until two hours after beginning iodine injection (lower penetration factors might have be found for measurements earlier in the test sequence), the above short-term results provide a conservative estimate of penetration factors following a step increase in radioiodine concentrations in conventional transport lines. The equilibrium value provides a conservative estimate for longer term sampling of normal concentrations.

Much smaller penetration factors were found for a few tests of systems with long transport lines of 6 mm (1/4 in.) diameter tubing when operated at flowrates of less than 1.7 liter/min (0.06 cfm). Some accident air sampling systems used this design to reduce the potential dose at the sample collector by using a low sample flowrate and a small diameter transport line. Tests simulating such systems (Unrein et al. 1985) showed very poor penetration of the radioiodine to the collector. Consequently, many of these systems were redesigned to collect a low flowrate subsample from a high flow, large diameter transport line to take advantage of its favorable sample penetration from the stack. An example of the effect of flowrate on the penetration of I_2 in a small diameter transport line is shown in figure C.2.

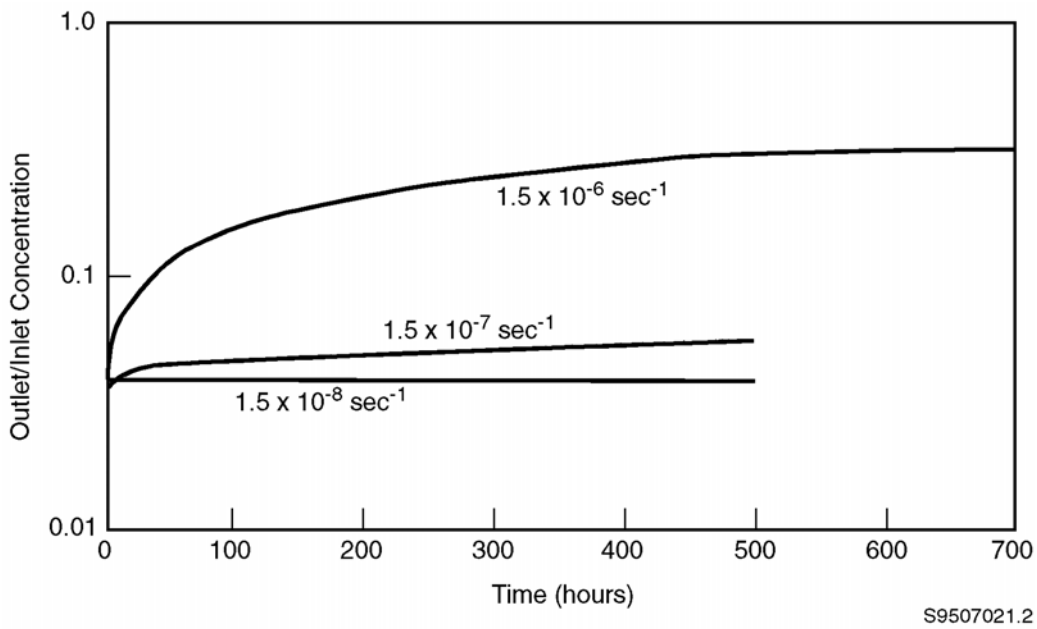

Figure C.1 – Predicted penetration of radioiodine as a function of time for various resuspension rates

The foregoing applies primarily to the transport of elemental radioiodine and, to a lesser extent, to the hypoiodous iodide form. Radioiodines in organic form, with their much lower deposition velocities, may be expected to be transported with higher efficiencies, thus making the above estimates additionally conservative. As summarized in Glissmeyer and Sehmel (1991), the fraction of organic radioiodine during normal operations appears to be quite variable from facility to facility, and there are no data on which to estimate the fraction that might be anticipated in the facility effluent during upset or accident conditions. Initially the predominant radioiodine forms during upset or accident conditions will be elemental or particulate.

C.3 Collection media for radioiodine

While carbon is an efficient collector of I_2, it is much less efficient for the low deposition velocity organic iodines. Kovach (1992) has indicated that the removal mechanism of elemental iodine on carbon adsorbents is primarily by physical absorption, the removal of hydrogen iodide (HOI) by physical absorption, chemical reaction and isotopic exchange, and that the removal of organic iodides such as CH_3I is by isotopic exchange. To improve the latter process, carbon filter media treated with potassium iodide (KI) or triethylene-diamine (TEDA) should be utilized. Packages with different types of adsorbents in series are available for the collection of radioiodine with separation by chemical form.

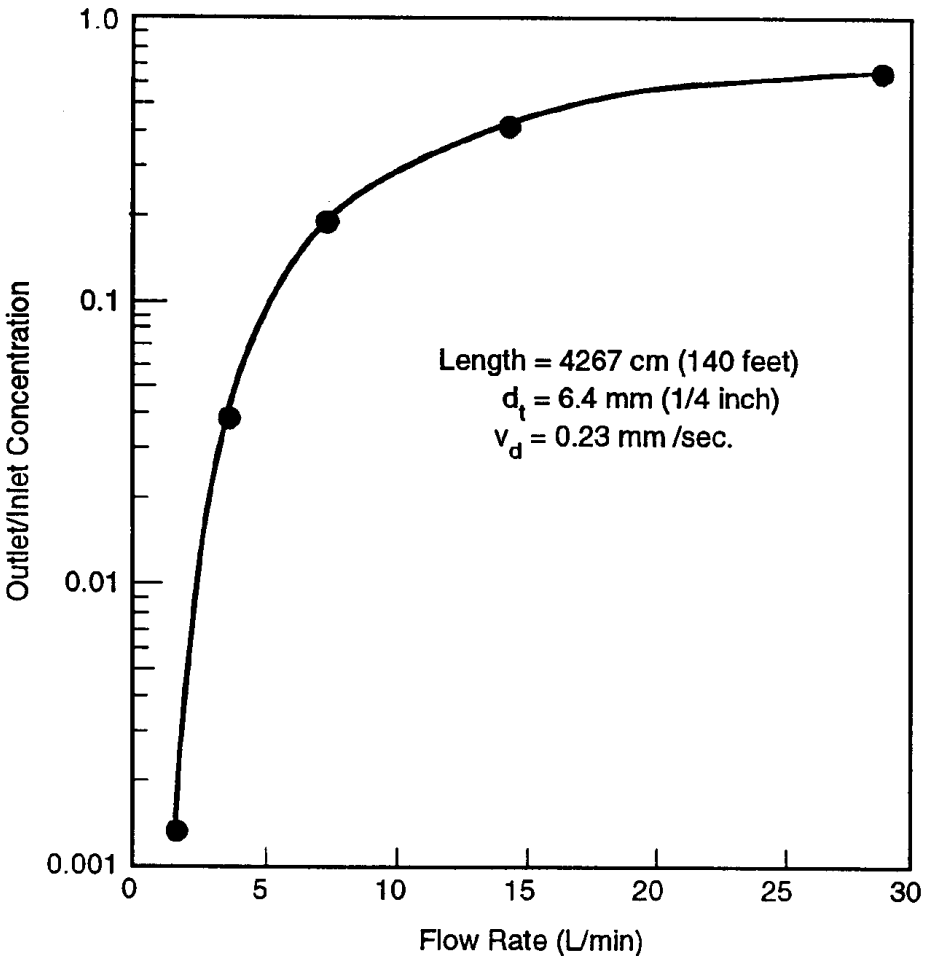

Figure C.2 –Predicted initial radioiodine penetration through a stainless steel transport line. Tube size: 6.4 mm (1/4 in.) inside diameter by 43 m (140 ft) long.

Annex D
(informative)

Illustration of criteria for optimizing the selection of filters for sampling airborne radioactive particles

Table D.1 summarizes the type of information that is useful for selecting an appropriate filter for sampling airborne radioactive particles. The table includes a variety of coarse fiber, glass fiber, and membrane-type filters, but does not constitute an endorsement of any particular manufacturer or filter type. Conversely, the absence of any particular filter from the example table does not constitute a rejection of that media. For general sampling applications, information is provided on durability, flow resistance, and efficiency. Information on collection of radon decay products and resolution for alpha spectroscopy is included for alpha continuous air monitor (CAM) applications. The alpha spectroscopy resolution is based on detection of the 6.0-MeV alpha emission of ^{218}Po (a naturally-occurring decay product of ambient ^{222}Rn, which causes interference in instruments used to detect plutonium or uranium isotopes).

Filter efficiencies range from >99.999 at all particle sizes and flowrates for the Millipore type AA, 0.8 μm pore size membrane filter to <50% for the Whatman 41 cotton cellulose filter at low flowrates and small particle sizes. Typical flowrates range from as low as 4 liter/min per cm^2 at 35 kPa (5 psig) pressure drop for the Millipore Type AA membrane filter to as high as 59 liter/min per cm^2 for the Millipore Fluoropore, 5 μm pore size Teflon membrane filter. Resolution for alpha spectroscopy of the ^{218}Po alpha emission at 6.0-MeV ranges from as low as 350 keV (full width at half maximum) for the Fluoropore 3 μm Teflon membrane filter to greater than 1500 keV for the Whatman 41 cotton cellulose fiber filter. The poor resolution associated with the Whatman 41 filter makes that filter unsuitable for use in continuous air monitors that are employed to detect plutonium or uranium in the presence of ambient radon decay products. In addition, although the Whatman 41 is easily dissolved for chemical analyses, it has a collection efficiency that decreases dramatically at low flowrates. The Fluoropore filters have very low pressure drop, good collection efficiency, and excellent resolution for alpha spectroscopy, but are not readily dissolved for radiochemistry. Selection of the larger pore 5 μm Fluoropore filter over the 3 μm pore option provides a substantial improvement in flowrate, with only a modest decrease in sampling efficiency and resolution for alpha spectroscopy.

As new filter types become available, comparisons such as these can be made by the user to ensure that appropriate filter types are selected for sampling radioactive aerosols.

Annex E
(informative)

Evaluating effluent sampling errors and uncertainty

E.1 Introduction

Error in the determination of a quantity such as the amount of radioactivity emitted from a stack during a certain period can be defined as the difference between its actual value (in some sense) and the measured value. Yet the real situations in which both the actual value and the measured value are known are typically those found when calibrating or qualifying a measurement procedure or instrument against standards, baseline data, or against one of the basic conservation laws of engineering. In most situations, it is the limits of uncertainty that might bound the possible errors that are quantifiable (Moffat 1988). Our understanding of the errors that contribute to the uncertainty in a measurement involve both fixed (bias) errors and random (precision) error. An estimate of the limits of uncertainty is required for a measurement that properly and completely combines both sources of error (ANSI/ASME PTC-19.1 - 1985).

The case of a simple stack effluent measurement system, such as a filter air sampler (FAS) connected by a transport line to a nozzle, will be used to illustrate a typical effluent measurement process. To estimate the amount of radioactivity emitted from a stack a sample of the effluent is extracted, transported to a collection medium, then collected. It is further necessary to quantify the collected material, then relate the quantified amount to the effluent. For the estimation of the effluent concentration, it is necessary to know or estimate the effluent flowrate, the area of the sampling plane, the sample flowrate, the nozzle transmission, the mixing ratio of constituents in the duct, sample transport penetration, sample collection efficiency, and analysis efficiency.

The sampling and analysis processes contribute both fixed and random error to the overall uncertainty in the estimated radioactivity. In the case of the extraction plane parameters and instrument calibrations, both bias and precision errors are combined into one uncertainty carried into the operation phase. For example, during the calibration of the measurement devices, a known and constant input is presented and output or measured response is observed. Fixed errors are evidenced by offset of the mean value from the expected standard response, and variable errors by variation in the output. In other elements such as the nozzle inlet or transport line, calibration is not possible, but performance in tests with standard aerosols under known, controlled conditions can be conducted to establish bounds on expected performance. Similarly, uncertainty estimates can be put on parameters such as the area of the sample extraction plane, the degree of mixing of contaminants at the plane, and the mean axial velocity of effluent through that plane. Calibration removes part of the fixed error but not the uncertainty.

The fixed errors that remain embedded in the predetermined parameter or calibrated device elements are not fully known in a particular application. Bounds can be placed on the embedded errors. The random components of error arise during the calibration measurement processes. These are estimated by the standard deviation of the variable measurement component, such as the sample flowrate or the radioactivity in the sample. Such standard deviation estimates are derived from the data alone without external reference.

Table D.1 –Characteristics of filters evaluated for use in sampling radioactive particles
(adapted from Hoover and Newton 1992)

Filter Type	Filter Composition and Durability	Typical Flow Rate (L/min per cm^2)[a)]	FWHM of the ^{218}Po PEAK (keV)[b)]	Relative Radon Progeny Counts in the Pu ROI[c)]	Relative Radon Progeny Collection Efficiency[d)]	Filter Efficiency Range (%)[e)]
Millipore Type SMWP (5.0 Φm pore size). Millipore Corp., Bedford, MA	Mixed esters of cellulose acetate and cellulose nitrate (fragile; electrostatic; both sides similar)	16	670	1	1	98.1 to >99.99
Millipore Type AW19 (5.0 Φm pore size). Millipore Corp.	Homogeneous microporous polymers of cellulose esters formed around a cellulose web (rugged; both sides similar)	16	470	0.57	0.99∀0.01	99.93 to > 99.99-
Durapore (5.0 Φm pore size). Millipore Corp.	Polyvinylidene fluoride (rugged; both sides similar)	14	790	1.55	0.67∀0.01	-
Fluoropore (3.0 Φm pore size). Millipore Corp.	Polytetrafluoro- Ethylene bonded to polypropylene high-density fibers (rugged; front is membrane; back is fibers; sides barely distinguishable by naked eye)	23	350	0.47	1.04∀0.02	98.2 to > 99.98
Fluoropore (5.0 Φm pore size). Millipore Corp.	Polytetrafluoro-Ethylene bonded to polypropylene high-density fibers (rugged; front is membrane; back is fibers; sides distinguishable by naked eye - high contrast backing)	59	460	0.67	0.96∀0.04	98.3 to > 99.99

Versapor 3000 (3.0 Φm pore size). Gelman Sciences, Ann Arbor, MI	Acrylic copolymer on a nylon fiber support (rugged; both sides similar)	25	590	0.94	0.75∀0.02	99.7 to > 99.99
Gelman Type A/E (–1.0 Φm pore size). Gelman Sciences	Borosilicate glass fiber without binder (breakable during handling; both sides similar)	25	∃ 1000	1.31	0.92∀0.01	99.6 to > 99.99
Whatman EPM 2000. Whatman LabSales, Hillsboro, OR	Borosilicate glass microfiber without binder (breakable during handling; both sides similar)	20	∃ 1000	1.48	1.00∀0.03	–
Whatman 41. Whatman LabSales	Cotton cellulose filter paper (rugged; currently used primarily for liquid filtration; both sides similar)	25	∃ 1500	1.65	0.42∀0.01	43 to > 99.5
Nuclepore, (0.6 Φm pore size). VWR Scientific, Pleasanton, CA	Polycarbonate membrane (rugged; thin; very electrostatic; currently used primarily for liquid filtration; collection side recommended by manufacturer is the shiny side)	4	500	0.89	0.85∀0.02	53 to > 99.5
Millipore Type AA (0.8 Φm pore size). Millipore Corp.	Mixed esters of cellulose (fragile; electrostatic; collection side is darker)	7	520	0.91	1.05∀0.01	99.999 to > 99.999

[a] Flowrate determined under vacuum at 35 kPa (5 psig).
[b] FWHM is the typical full width at half maximum of the ^{218}Po peak obtained with a 2.5-cm diameter filter and a 2.5-cm diameter solid state detector with a 0.5-cm separation distance during sampling of room air at the Inhalation Toxicology Research Institute in Albuquerque, NM.
[c] Radon progeny background counts in the Pu ROI for the filter of interest, divided by similar counts obtained simultaneously on a Millipore SMWP filter.
[d] Total radon progeny background counts on the filter of interest, divided by similar counts obtained simultaneously on a Millipore SMWP filter. Mean and standard error for five replicate tests.
[e] The range of filter efficiency values given generally correspond to a particle diameter range of 0.035 - 1 Φm, a pressure drop of 1 - 30 cm Hg, and a face velocity range of 1 - 100 cm/s. Values are from Liu et al. (1983), Liu (1992), Hoover et al. (1997a), and Hoover et al. (1997b).

E.2 Contaminant transport uncertainty estimation

Regulatory limits on radionuclide emissions are generally stated in terms of limits on the resultant dose to members of the public per year. Thus a facility sampling and measurement system must generate an accurate and reliable estimate of quantities emitted in a given sampling interval that can then be input to an environmental transport and dose estimation model. The quantity of radioactive substances being transported out of a stack can be represented as:

$$E \approx c_A U_M A. \tag{E-1}$$

where: E is average radionuclide stack emission rate over the period of integration, Bq/s; A is area of the sample extraction plane in the stack, m^2; c_A is effluent radionuclide concentration, Bq/m^3; and U_M is mean axial effluent velocity in the stack, m/s.

The first term of equation (E-1), the effluent radioactivity concentration, is determined by radioactivity measurement, measured sample volume, and constant parameters of the system:

$$C_A = \frac{r_n}{Q\,P\,M_p\,\varepsilon_f\,\varepsilon_d} \tag{E-2}$$

where: r_n is net counts per minute (gross minus background) from the sample, cpm; Q is volume of effluent that produced the sample at stream temperature, pressure, and gas composition, m^3; P is the overall penetration of sample from the free stream to the sample collection medium (combining transmission through the nozzle, T_p, and through the transport line, T_L): the ratio of concentration at the output of the sample transport line, to the effluent free stream concentration; M_P is mixing of radioactive contaminant in the total effluent gas volume, determined as the ratio of the concentration in the sample volume to the concentration in the free stream, fraction; ε_f is collection efficiency of the collection medium, fraction; and ε_d is detection efficiency, cpm/Bq.

The second term of eqn (E-1) is the average effluent flow velocity, typically determined by preoperational measurements from traverses across the duct. Other methods and devices might be used such that near-real time data for U_M are developed.

Assuming that EPA Method 2 is used, the mean axial velocity of the effluent is computed from the results of multiple velocity determinations, one at each subsection of the traverse pattern over the sampling plane. Once again, this determination is made during site qualification and subsequent verification, not during operational phases. The relation between U_M at a particular location, and actual parameters measured with a pitot tube is

$$U_M = U\cos(\theta) = C_P\cos(\theta)\sqrt{\Delta p/\rho} \tag{E-3}$$

where: C_P is pitot calibration factor; Δp is differential pressure; ρ_g is gas density, gm/cm^3. Gas density is determined from measured static pressure, molar mass of the gas, and temperature through the equation of state; and $U\cos(\phi)$ is measured velocity corrected for flow angularity at angle ϕ.

The last term of eqn (E-1), the flow cross-sectional area A, will also have been predetermined from blueprints or from measurements across the stack or duct. That area is divided into subsections of equal area for purposes of measuring an average axial velocity.

Combining eqns (E-1) and (E-2), the stack emission rate equation for $E_{average}$ (Bq/sec) is:

$$E_{average} = \frac{r_n \; C_P \; \cos\Theta \; \sqrt{\Delta p / p} \; A}{Q \; P \; M_p \; \epsilon_f \; \epsilon_d} \qquad \text{(E-4)}$$

Eqn (E-4) is the mathematical model of the emissions measurement.

E.3 Quantifying uncertainty

E.3.1 Stack emission measurement uncertainty analysis methods

An emission release rate is a function of a large number of measured parameters contained in eqn (E-4). A basic analysis of uncertainty can be carried out under the assumption of near-normal distribution of random errors, which is valid for most, but not necessarily all of the variable parameters involved.

E.3.2 Overall uncertainty associated with the measurement process

An uncertainty analysis of explicit errors associated with measurement processes that take place either in the pre-operational or operational phases has been developed. Each of the terms in the convective emission model has been examined and expanded as appropriate. This is a recommended approach rather than attempting to write a single complex error equation. The total emission rate from the stack is calculated from radioactivity measurements on a continuous sample extracted from a qualified sampling location, and other measurements of parameters of the emission equation. The overall uncertainty in that number can be estimated by summing over each of the terms of an uncertainty equation (Moffat 1988).

E.3.3 Uncertainty associated with fixed errors

The several components of fixed uncertainty in an emission measurement can be combined in one term. An overall bias limit, B_L, defined as the maximum probable value of the total fixed error in the measurement estimated at the 95% confidence level, is the root-sum-square combination of all fixed error components. These can be classified as calibration bias, B_{CAL}, parameter estimate bias, B_{PAR}, and design and test bias for components such as nozzles and transport lines, B_{TST}:

a. The calibration bias term, B_{CAL}, represents the fossilized overall calibration uncertainty, combining both elements of bias and random error that accrue during calibration of instruments or devices. This is typically the residual bias remaining after gross bias is zeroed out (up to an acceptance limit) during calibration, and in some cases is identified by manufacturers as the accuracy limit of the calibrated scale or readout device.

b. The parameter bias term, B_{PAR}, represents the overall uncertainty (again combining fixed and random error estimates) that derives from field and laboratory determinations of sample extraction parameters such as the degree of particulate mixing M_P or mean profile velocity U_g that ultimately are applied as a single value to estimations of stack emissions. Other fixed error contributions related to sampling location effects are treated separately below.

c. The design and test bias term, B_{TST}, results from residual uncertainties in the process of design and qualification of sampling nozzles and devices that are engineered from first principles and empirical factors, and then manufactured and tested to confirm that certain performance characteristics, such as nozzle inlet penetration efficiency for 10 μm AD particles, have been met. Such a critical performance characteristic is specified by an acceptable range for a given set of operating conditions, and there is an acceptance limit on deviation between the design performance and the result of confirmation tests with tracer materials.

The overall bias limit then can be expressed as:

$$B_L = \left(\Sigma_i B_{CAL}^{\ 2} + \Sigma_i B_{PAR}^{\ 2} + \Sigma_i B_{TST}^{\ 2} \right)^{1/2} \qquad \text{(E-5)}$$

where the summations are over the several contributions from devices or parameters contributing fossilized uncertainty to the measurement outcome.

The bias limit estimated at the 95% confidence limit serves the same purposes for the fixed error as does the two standard deviation random error estimate. It is combined with the 95% confidence limit estimate of the random error component in calculating the overall uncertainty of measurement. A full uncertainty analysis entails a careful consideration of the many sources of uncertainty and proper combining of each component to generate an overall uncertainty estimate.

The table 3 guidance levels for acceptable accuracy and precision of measurement require evaluation of factors that can contribute error to components of the system. Without detailed analysis, it may be difficult to demonstrate that estimates are reasonably complete and defensible. The following discussion is meant to provide a framework for an evaluation of uncertainty in effluent measurement based on an analytic expression relating radionuclide emission to variable parameters in the measurement, and on residual bias and implicit errors inherent in the methodology of continuous emission monitoring from a single point.

Recalling that the error in a measurement is defined as the difference between its true value and the measured value, it is worthwhile to reflect here on what interpretation should be given to the "true value" of measured effluent radioactivity emission rate by the single point representative sampling method. If we use the classification and nomenclature developed by Moffat (1988), the fact that flow and mixing parameters are averaged over the profile entails that the intended "true" emission rate is the "conceptual value" at the sampling location: the area-averaged emission rate of radioactivity from the stack based on single point sampling at the axial location of the single nozzle, assuming the installed instrumentation does not disturb either the concentration or the flow distributions, and that the pre-operational measurements of critical parameters (i.e., U_M, P, Q, and M_p) properly reflect sampling under operational conditions. The conceptual value is to be distinguished from the "available value," which would be the emission rate estimated only at the axial location of the nozzle (without assumptions about disturbance, mixing, or how representative the parameter estimates are). Because we are interested in the well-mixed mean effluent radioactivity emission rates, the effects of velocity and contaminant mal-distribution must be added to the list of sources of error, and uncertainties in the correction factors that account for the mal-distribution must be considered. The estimation of the true emission rate (the conceptual value) depends on parameters measured at other times, under possibly different conditions, and with test aerosols and gases rather than the actual radioactive contaminants, so it is evident that the uncertainty in the result a single point sample depends on other considerations than explicit operational or pre-operational measurement uncertainties.

E.3.4 Uncertainty associated with conceptual errors

As noted in clause 4.4, a useful distinction can be made between the errors of the measurement processes and those associated with the overall methodology. The measurement errors are attributable to explicit performance aspects of the sampling and analytic hardware. Sampling methodology errors derive from issues related to sample extraction location and related implicit factors that affect how well the sample represents the true emissions from the stack during the period of the sample. These are what Moffat (1988) terms "pattern factors" defined as factors that describe variation in velocity and mixing in the profile and an estimate of how the value of the emission rate at the nozzle location compares with the mean value. In some situations the conceptual errors can be the largest by far. Two of the more significant sorts of conceptual errors derive from assumptions about temporal variation and about the completeness and accuracy of model assumptions.

E.3.4.1 Errors associated with temporal variations

Changes over time in stream conditions following site qualification are assumed not to significantly influence the measurement outcome. Yet, increases or decreases in volumetric sample flow, effluent discharge rate, or modifications in the stack use can cause distortions in sample extraction or contaminant mixing. The degree of how representative a single point sample is, could then change. That is why it is particularly important that whatever factors are counted upon to produce a well-mixed condition at a qualified sample extraction location should be robust with respect to reasonably anticipated changes in stack conditions. Mechanical mixing elements or deflected, colliding flows produce mixing conditions at the selected sample extraction plane that are resistant to change under modifications in facility use or under upset conditions, and so their use would support a small value of estimated uncertainty δ_{TE}. A judgement will be required about assigning the significance of temporal variations and hence the magnitude of this uncertainty term.

E.3.4.2 Model errors, δ_{ME}

There are a number of simplifying model assumptions implicit in the representation of continuous emission monitoring by extractive sampling from a single point. Among these are that the contaminant transport processes in the sample nozzle and line are well represented by semi-empirical models in the DEPOSITION code or similar code, that the measured uniformity of the velocity profile and degree of mixing at the stage of site qualification will continue to apply during operations (a pattern assumption), and that the radioactivity measuring process is well represented by single parameter sample collection and radiation detection efficiencies. To varying degrees, model-based assumptions may not be fully correct for a particular application. Again, a judgement is required to assign an estimate to this uncertainty term. Both the temporal variation uncertainties and model errors can be combined with other fixed errors arising from various measurements in generating an overall bias limit estimate.

The user is advised to become very familiar with the assumptions and modeling limitations of the DEPOSITION code or any other code used to optimize sample transport line design to be sure that special concerns for deposition of highly reactive species, particle bounce, or resuspension from previously deposited materials are properly accounted for. The same applies to models of other aspects of the sampling and measuring process. The use of computational modeling aids should be viewed as a part of a larger process of design and evaluation that should include data from laboratory studies, findings in the peer-reviewed literature, and field testing.

E.3.5 Describing the combined uncertainties in emission measurement

The last step of an uncertainty analysis is bringing together the 2σ random errors and the overall bias limit (eqn E-1) into a combined estimate of overall uncertainty in the emission estimate:

$$E_{total\ (0.95)} = (B_L^2 + \Sigma_i 2S_i^2)^{1/2} \tag{E-6}$$

where: $E_{total\ (0.95)}$ is the estimated error limit of the effluent measurement at the 95% limit (ANSI/ASME PTC 19.1-1985); B_L is the expected upper limit of the total true bias error (the difference between the average of the total population and the true value, which is the true systematic or fixed error); and S_i is the sample standard deviation based on N measurements of the I-th term (precision index) for variable terms in the emission rate equation.

E.4 Evaluation of errors

Following Brooks (1979), estimates of the magnitude of most of the error terms can be described at least to the level of what is attainable at the 95% confidence level (corresponding to a $\pm 2\sigma$ interval for random variables). Many of the errors considered above are relatively small and controllable by good practice. Others require more careful consideration.

E.4.1 Errors in sample volume, stack area, and transmission efficiency

Errors in sample volume *Q*, and stack area *A*, are generally small and well understood. Sample volume measurement is readily accomplished and corrected for altitude and temperature. As described in clause 7, the accuracy of measurement of sample flow (and hence sample volume) with a flowmeter should be periodically checked with a secondary standard flowmeter, and differences maintained to less than 10% of standard (see clause 7, eqn 11 for further details); 2σ random errors on the order of 5% should be achievable.

The cross-sectional area of the effluent flow at the sample extraction location should be accurately ascertained from engineering drawings of the effluent stack. Fixed errors associated with this determination should be much less than 2%.

Sample transport line penetration in the case of particulate effluent is harder to estimate because the characteristics of the aerosol being sampled cannot be fully described in advance. Although the particle size characteristics of many types of radioactive aerosols have been studied (see annex H for a discussion of such studies), many possibilities for HEPA filter failure and associated unique aerosol size distribution exist. Nonetheless, an estimate of the magnitude of error in this parameter can be made. First, the minimum acceptable transport line efficiency for 10 μm AD particles has been established at 50% (clause 6). It is expected that a proposed transport line for a sampling system would be designed for optimal performance using the DEPOSITION code (or equivalent) (annex B). If practical, the performance of the as-built system should be verified by laboratory testing with 10 μm monodisperse test particles. If in-stack field performance is estimated by simulating penetration of a characteristic polydisperse aerosol through the nozzle and line, then errors associated with the use of the predicted transport efficiency can be derived.

Consider for example the sample line described by Anand et al. (1993) in the DEPOSITION manual. It consists of a nozzle with a 0.2 m section feeding a 2-m horizontal tube through a 90° bend, followed by a 2 m horizontal tube connected to a vertical 2-m tube by a second 90° bend. For monodisperse 10 μm particles, the penetration is predicted by DEPOSITION to be 55.2%, which would qualify the system. Now assume there is a polydisperse log-normal distribution of particle sizes with an average activity median aerodynamic diameter (AMAD) of 1.8 μm and σ_g = 2.2, like that found in a research and development facility glovebox line by Ettinger et al. (1973). The DEPOSITION predicted penetration rises to 94.2%, a 70% increase. The user may assume the penetration of the system is the more realistic estimate for polydisperse aerosols rather than the conservative value based on 10 μm tracer tests, or make further field measurements with polydisperse test aerosols. For error analysis purposes, suppose the aerosol actually encountered in an accident effluent is more like a fabrication facility average size distribution (AMAD of 4.0 μm, σ_g = 1.7) reported by Ettinger et al. (1973). Then the penetration is predicted to be 85.9%, a relative difference of 8.8% compared with the 94.2% estimate. The average predicted deviation using a range of size distribution parameters from four other plutonium handling facilities included in their study is 7%. A 15% estimated 95% confidence level error relative to predicted performance assuming a realistic aerosol size distribution appears to be attainable. These estimates are summarized in table E.1.

E.4.2 Errors in velocity measurement parameters

Errors in the determination of velocity at each equal area location in a profile are summarized from Brooks (1979) in table E.2, assuming that an S-type pitot tube nozzle is used. Here, as in the case of the parameters of table E.1, attention to the details of the design and operation of the hardware in use is required.

E.4.3 Errors in radioactivity measurement parameters

Measurement of radioactivity in a sample can either be an on-line process in a continuous monitor, or off-line process in a laboratory. In either system, detector efficiency and sample capture efficiency parameters can usually be well defined. Detector efficiency is typically determined by comparison against a transfer standard traceable to NIST. Fixed errors can be held to a minimum (1-2%).

Table E.1 –Errors in sample volume, stack area, and transmission line efficiency

Parameter	Error
Sample volume, $2\sigma_Q/Q$ x 100%	± 5%
Stack area, $2\delta_A/A$ x 100%	± 2%
Transmission line efficiency, $2\delta_{Tp}/T_P$ x 100%	± 15%

Table E.2 –Velocity measurement parameter errors

Parameter	Error

Pitot calibration: $2\delta_{Cp}/C_p$ x 100%	± 1%
Flow angularity: 2 tan(θ)δ x 100%	± 8%
Differential pressure: $2\delta_{\Delta p}/\Delta p$ x 100%	± 14%

Poisson errors in the radioactivity counting process and random errors associated with background interference variability are the largest contributors to this error parameter. However, bounds can be put on these errors by careful planning.

In most circumstances, a relative 95% confidence level error of 5-10% appears to be attainable by adjustment of sample and background count times. But this may not always be possible due to unrealistically long count intervals that will result.

E.4.4 Methodological errors

Turning now to the implicit methodological or conceptual uncertainties, there is a large component of engineering judgment required to assign values to these, but bounds can be placed on the estimated uncertainty.

The representativeness of the sample withdrawal location, for example, can be estimated by the measured coefficient of variations in mixing of tracer gas and tracer particles that are required as part of qualifying a sample extraction location for continuous emission single point sampling and monitoring. Based on limited studies, it appears that a 95% confidence limit error of δ_{RE} = 10% is attainable, and in any event should be much less than 20%.

Random errors associated with changes in effluent emission conditions over time are difficult to predict. If mixing elements installed in a stack are employed to assure complete mixing, then an estimate of the 95% confidence limit on uncertainty due to time varying effects on the order of δ_{TE} = 2 - 4% appears to be reasonable.

Similarly, model assumption uncertainty, at the 95% confidence level, on the order of δ_{ME} = 2 - 4% is feasible as long as proper qualifications of the sampling nozzle, sample transport line, and sample withdrawal location are demonstrated.

E.5 Summary of error analysis

Estimated uncertainties in tables E.1 and E.2 (or equivalent from an independent analysis) and the other parameter uncertainty estimates can be substituted into appropriate equations to obtain a total explicit measurement process uncertainty estimate. The estimated radioactivity measurement error term (5.5%), sample volume measurement error (5%), and sampling plane area uncertainty (1%) contribute least to the total. Sample transport line efficiency uncertainty (15%) and emission mean axial velocity uncertainty (10.7%) terms contribute most. The resultant combined uncertainty is on the order of 19%.

Combined with the conceptual uncertainty estimates, the overall effluent radioactivity measurement uncertainty estimate is:

$$E_{total\,(0.95)} = \pm\sqrt{(0.19)^2 + (0.07)^2 + (0.02)^2 + (0.02)^2}\ \mathrm{x}\,100\% = \pm 20\% \qquad \text{(E-7)}$$

This estimate should be understood as an indication of what might be attainable based on the assumptions concerning the measurement procedures carried through the analysis. Differences in the way mean axial velocity is determined, improvements in reducing errors in volumetric flow measurement, and better potential transport line loss estimation could be made in some cases, as could reductions in uncertainty in certain of the profile "pattern" parameters such as any of the statistics describing mixing at the sampling plane.

E.6 Correlated errors

The analysis to this point has been under the assumption that the errors are separable. The errors are not separable in all cases. The transport efficiency, T_s, and the collection efficiency, ε_f, are dependent upon the flowrate. In some cases, the detection efficiency is dependent on the flowrate.

Based on the uncertainty analysis of eqn (E-4) it may be concluded that the flowrate uncertainty is ignorable. Flowrate uncertainty may be ignorable based on its intrinsic uncertainty, but not on its extrinsic or correlated uncertainty.

The transport penetration is dependent upon the flowrate. If high transport penetration (>90%) is the case for all particle sizes, flowrate changes of 10% or less may have little effect on the transport efficiency. When the transport penetration is lower, small changes in the flowrate may greatly effect the transport efficiency for some particles sizes. These changes should be empirically determined or calculated using a code such as DEPOSITION. A similar relationship for particle collection can be developed. The same correlated uncertainty arguments pertain.

The detection efficiency can be affected by the flowrate if detection is dependent upon geometry and the geometry is collection-dependent. A simple example is alpha particle detection on a filter. If collection of large, high-activity particles takes place primarily near the edge of the filter and, therefore, the edge of the detector, then detection efficiency for these particles will be diminished. The flowrate-correlated uncertainty should be determined.

Flowrate-correlated uncertainties in these cases are further dependent upon the particle size distribution, i.e., on a few large particles may have little effect, while a dominance of large particles may have dominant uncertainties.

Annex F
(informative)

Sampling system performance verification

F.1 When to conduct sampling system performance verification

There are instances when a performance verification of a sampling system is advisable. These include:

a. Before a new system becomes operational;

b. When an existing system that has just come under additional regulatory requirements;

c. When an existing system where the potential to emit contaminants has changed significantly;

d. When an existing system where there has been significant changes, for example: changing the stream flow beyond the original design limits, adding a new effluent stream in a manner that destroys the well mixed state at the nozzle location, or changing system operating parameters outside of the design range;

e. When the supporting documentation for a newly installed system is deficient.

F.2 Approaches to verification

The methods for verifying sample transmission performance through nozzles and transport systems fall into four categories:

a. In-place testing;

b. Laboratory simulations;

c. Modeling based on deposition and resuspension rates determined in the laboratory;

d. A combination of the above.

Table 4 of this standard summarizes the requirements for qualifying sample extraction locations, nozzles and transport lines for particles, gases, and vapors. Clause 6.3.2 requires that nozzle performance for particles be tested using a liquid aerosol. Clause 6.4.1 requires that transport line performance be assessed either through aerosol testing or through calculations with a verified model. Clauses 5.2 and 5.3 provide methods to be used for qualifying the sampling location for particles, gases, and vapors using in-place testing. Nozzle and transport line performance methods for gases and vapors are not specified in the standard.

Meeting the performance requirements will usually involve a combination of methods. In-place testing may give the most unambiguous result, but may also be difficult to implement in all situations. The following discussion gives examples of methods in each category.

F.3 In-place testing

F.3.1 Particle sampling examples

Rodgers et al. (1996) provide the most recent example of employing the methods outlined in clauses 5 and 6. Sulfur hexafluoride gas and oleic acid aerosols were the tracers used to qualify the sample extraction location. The oleic acid aerosol was also used to verify the performance of nozzles and transport lines for particles. Other verification examples include the following:

a. Leuba and Schwabacher (1961) used 3-30 μm aluminum and iron powder aerosols;

b. Schappel (1961) used uranium aerosols;

c. Ström and Hesböl (1977) used fluorescent dye-tagged dioctyl-phthalate 20 μm aerosol;

d. Curtis and Guest (1986) used submicrometer sodium fluorescein dye aerosol;

e. SAIC (1991) performed tests on several stacks using polystyrene latex microspheres and optical particle counters sampling from the nozzle inlets and the exits of the transport lines;

f. Newton et al. (1983) conducted tests of the sampling systems at the Waste Isolation Pilot Plant using salt aerosols;

g. Glissmeyer (1992) tested systems using powdered tracer aerosols with geometric mean diameters of 1.3 μm and 8.5 μm. Temporary sample collectors were arrayed across the stack to characterize the mixing and to determine the average emission rate for comparison against the existing system;

h. Kenoyer (1993) used cascade impactors and optical particle counters in tests of several systems without employing tracer aerosols.

F.3.2 Radioiodine sampling examples

Ström and Hesböl (1977) tested sampler performance for radioiodine by injecting both depositing and nondepositing forms of iodine into the ventilation stream. Samples were collected both in the stack at the elevation of the sampler nozzles and at the regular sample collection point. The nondepositing form was ^{131}I-tagged methyl iodide and $^{131}I_2$ was used as the depositing form.

Curtis and Guest (1986) used stable methyl iodide and elemental iodine injected into the stack flow upstream of the fan. Collected iodine samples were analyzed using neutron activation.

Leuba and Schwabacher (1961) used ^{131}I injected into a stack that was sampled at several locations in the cross section using charcoal traps. Together with velocity data and tracer aerosol tests, the contaminant profiles for the stack were obtained.

F.4 Laboratory simulation

Laboratory simulations are more rapid and convenient than in-place tests. It is unlikely that complete systems can be simulated, and the effects of surface contaminants in older systems may significantly effect real performance.

F.4.1 Particle examples

SAIC (1991) conducted a test of a full-scale sampling system of simple design. The tests were conducted using polystyrene latex microspheres laser particle counters sampling from the nozzle inlet and from the end of the transport line. McFarland et al. (1991) conducted tests of a simulated sampling system using sodium fluorescein tagged oleic acid aerosol.

F.4.2 Radioiodine examples

Unrein et al. (1985) and Edson et al. (1987) conducted radioiodine line-loss tests to simulate air samplers used at several nuclear generating stations. The tests cover the range of air sampler characteristics commonly observed at reactor sites. The sample transport tubes were either 304 or 316 stainless steel as clean as received from the distributor. The results from these and other tests were summarized by Glissmeyer and Sehmel (1991).

F.5 Modeling

Modeling is often used to address the performance of transport lines. Modeling does not completely address all performance aspects of a sampling system, notably the adequacy of contaminant mixing at the sampling plane. This weakness may be overcome in the future as illustrated by Gielow and McNamee (1993) who used a three-dimensional fluid mechanics model to identify potential flow measurement locations in a power station offgas ductwork. They also compared model results against velocity traverse data.

F.5.1 Particle examples

Fan et al. (1992) provides an example of the use of the DEPOSITION code and compares the results against tests of a simulated air sampling system. Examples of the use of earlier models include Rodgers (1987), Alvarez et al. (1985), and Schwendiman et al. (1975). Annex B describes most of the elements that need to be taken into account in a particle loss model.

F.5.2 Radioiodine examples

SAIC (1991) modeled the radioiodine transmission through several sampler transport lines. Other examples are summarized by Glissmeyer and Sehmel (1991). (See also annex C.)

Annex G
(informative)

Transuranic aerosol particulate characteristics: implications for extractive sampling in nuclear facility effluents

G.1 Introduction

The engineering of stack monitoring and sampling systems for nuclear facilities requires close attention to the design and placement of the sample extraction nozzle and transport line to assure the most representative sample possible (McFarland and Rodgers 1993). With respect to the physical characteristics of the effluent that would have to be sampled under normal and especially emergency conditions, little has been said other than that the most significant accident in a facility in terms of both an event and an interacting agent is likely to be fire (Corley and Corbit 1983). The fire can cause radioactivity sources to release airborne radioactive aerosols, and the smoke can plug filtration systems causing the filter to lose its integrity by rupture of the medium or seals. Therefore, there are no definite answers concerning the aerosol characteristics that a sampling nozzle and transport line should be capable of handling. However, a number of investigations have been made of the expected filtration performance of HEPA filters under standard operating conditions. Also, a number of investigations have been made of the characteristics of aerosols present in glovebox confinement or generated when containment structures, flammable liquids, and commingled radioactive materials are spilled and burned. Because these aerosols would be expected to be present in a fire, they provide a first approximation of the character of aerosols that would have to be sampled in effluent stacks. The following discussion is meant to place some reasonable bounds on the size of particles that would typically be present in the event containment is lost and to provide some perspective on the type of design and testing considerations to be applied to sampling nozzles and transport lines.

G.2 HEPA filtration effects

Nuclear facility stack emissions are typically controlled by multiple stages of HEPA filters. The HEPA filter is designed to remove particulates from a gas stream with an efficiency of at least 99.97%. Selective penetration of HEPA filters by submicrometer size particles (d_p = 0.1 - 0.4 μm) and negligible penetration by other sizes of particles is predicted by filtration theory (Scripsick 1994). Therefore, it is sometimes concluded that it is not necessary to design sampling systems for HEPA filtered stacks that take into account inertial effects in the sampling nozzle inlet and transport line. However, this conclusion is invalid.

In studies at the Rocky Flats Plant of particulate emissions in stack effluents, Nininger and Osborne (1992) sampled for particles downstream of HEPA filters. A laser particle counter was employed to obtain number size distribution data over the size range from submicrometer to over 10 μm (optical diameter). There was observed to be only a small fractional percentage of particle counts corresponding to diameters greater than 5 μm, but when these data are converted to volume distribution (hence reflecting the actual distribution of particle mass, and possibly radioactivity, in the samples rather than number of particles) the volume percentages corresponding to particles with diameters greater than 5 μm were quite significant (greater than 30%). The authors observed the presence of white fibers in the vent discharge and speculated that the large particles may have been shed by the HEPA filters.

A different explanation for the presence of the larger particles downstream of HEPA filters comes from recent studies by Scripsick (1994) of leak phenomena in HEPA filters systems (pinhole leaks, frame seal leaks, etc.). Particle penetration through filter perimeter seals and the filter pack were determined separately and in

combination. Penetration was observed only when the challenge aerosol was introduced into the system, ruling out the possibility that the observed particles were shed from the filter pack. He found that whereas filtration theory predicts a penetration fraction of 10^{-16} for 0.7 μm particles, the observed penetration was approximately 10^{-5}. Scripsick concluded that system leakage phenomena and the size distribution of the challenge aerosol can surpass filtration theory considerations in predicting the size distribution of particles penetrating the HEPA filter systems.

This is consistent with studies of multiple HEPA banks by Ettinger et al. (1973), whose data are summarized in table G.1. Here the presence of a small but significant fraction of supra-micrometer sized particles beyond the second and third stage is indicated because the geometric standard deviations remain large. But the respective activity concentrations are very small due to the reduced challenge and narrowing spectrum of particle size at each successive stage. At the same time, failure of earlier stages would be expected to result in both higher release concentrations and larger quantities of particles in the inertial size range (1 μm AD and larger). Therefore, the design of extractive sampling systems in HEPA filtered stacks should reflect consideration of the presence of large particles, even under the presumption of normal operating conditions and HEPA filtration.

G.3 Transuranic aerosol characteristics under accident conditions

HEPA filter failure under a variety of accident conditions adds another dimension to the concern for being prepared to sample particulate radioactivity in larger size ranges. But now we must ask, if substantial HEPA failure occurs, what is the upper bound of particle size that one could expect to have to sample efficiently in order to properly represent the majority of the activity in the effluent? In other words, would the effluent aerosol at the sampling plane suddenly shift to one characterized by the occurrence of a significant particle size mode in a region beyond 10-15 μm AD? It is understandably difficult to characterize aerosols expected to be associated with HEPA failure. As is the case with normal, intact HEPA filter banks the characteristics of the aerosol penetrating a failed HEPA will be determined by the characteristics of the challenge aerosol. The literature derived from studies of aerosols associated with accidental spills and fires in nuclear facilities, and of *in situ* dusts and debris in uranium/plutonium gloveboxes and ducts, provides the best indications of what to expect. The following synopses of a few cases are indicative of what is known and expected:

1) In a study of plutonium particle sizes in air samples taken in operational areas at the Rocky Flats Plant many years ago, when maintenance operations on gloveboxes resulted in loss of containment (Kirchner 1986), operations such as machining, oxide crushing, and fluorination of plutonium were found to produce airborne particles with mass median aerodynamic diameters (MMAD) of 2-4.5 μm (assumed density of 11.45 gm/cm^3). Conditions related to glove failure on a plutonium metal burning box leading to worker exposure produced larger airborne particles having a MMAD of 13.8 μm. Kirchner noted that these data agree very closely with the activity median diameters (AMAD) of particles measured at the AERE radiochemical laboratories in Harwell, England by Sherwood and Stevens (1965).

Table G.1 - HEPA efficiency and particle penetration of plutonium aerosols

HEPA stage	Particle size AMAD[a)] of challenge (μm)	Mean measured efficiency (%)	Remaining activity (dpm/m^3) [b)]
1	0.7 - 2.1 σ_g = 2 - 3	99.99876	10^5 - 10^6
2	0.45 - 0.82, σ_g = 1.5 - 2	99.99817	10 - 10^2
3	0.37 - 0.70 σ_g = 1.3 - 1.8	99.86492	0.01 - 0.05

a) AMAD = Activity median aerodynamic diameter.
b) Challenge aerosol concentration 10^{10} - 10^{12} dpm/m^3.

2) Elder et al. (1974) placed sampling nozzles in process lines or gloveboxes under "worst normal" conditions (i.e., when aerosol generation as a result of routine operations was highest) in a study of challenge aerosol characteristics and the response of multiple HEPA filters. Facility operations included research and development activities, fabrication, and chemical recovery. Activity concentrations in challenge aerosols were in the range of 10^6 to 10^7 dpm/m^3. Fabrication operations produced fairly large aerosol particles (predominant AMAD of 3-5 μm AD), while recovery operations consistently produced particles in the submicron range (0.1-1.0 μm). Research and development operations generated particles predominantly in the intermediate range (1-4 μm). The largest reported size bracket in the log-normally distributed impactor data from all sites was a 10.9 μm bracket (normalized frequency of 4% by activity), from a research and development facility.

3) Apart from accidents, processing facilities age and contaminated structural materials can become suspended downstream of HEPA filter systems. The contamination can occur gradually or during process and filter upsets. Mahoney et al. (1994) summarized historical measurements of particle size distributions in a plutonium finishing and reclamation complex downstream of HEPA filter systems. The AMAD of plutonium-bearing particles ranged from 1.3 - 20 μm. Ventilation ducts damaged by exposure to acidic fumes can generate significant concentrations of slightly contaminated rust particles.

4) When accidental events are considered, the potential contribution of fire-generated aerosols should be included. In Pacific Northwest Laboratory studies of burning radioactively contaminated materials (Halverson et al. 1987), uranium was used as a surrogate for plutonium. Combustion aerosols containing uranium from contaminated plastics produced fairly large particles (1-5 μm MMD). Compounds in glovebox gloves (polychloroprene) produced the largest particles (19.9 μm MMD). Burning cellulose produced a wide range from <1 μm to as large as 10.5 μm MMD. Conversion of these numbers to aerodynamic diameter is uncertain due to unknown density and shape factors.

5) Accident conditions may involve leaks or spills of liquid and powder forms of radioactivity leading to airborne materials. In studies with uranium and other surrogates, Ballinger et al. (1988) measured particle MMDs in a wide range of between 3 and 20 μm MMD. Liquid spills appear to produce the largest particles from splash droplets that start large but get smaller as the liquid evaporates. Powder spills have more variability in particle size due to agglomeration effects in the bulk state.

6) Agglomeration in accident-generated aerosols have been shown to produce larger particles in a polydisperse aerosol of smaller particles. However, it would appear that this process does not yield extraordinarily large modes of particle size. Using data from ORNL's nuclear safety pilot plant experiments with burning sodium in a containment structure, Jordan (1986) predicted (and confirmed with observation) relatively stable mean aerodynamic diameter time behavior. Diameters remained below 5 μm AD for 5 days following release and confinement.

7) In some DOE facilities there is the potential for involvement of plutonium metal in fire scenarios. Studies have been made of the release of aerosols under reducing and oxidizing environments. Edison et al. (1988), for example, found that activity median diameters of plutonium aerosols generated from plutonium metal pellets and foils were variable, but ranged from 4 to approximately 10 μm AD.

G.4 Implications for nozzle design

The available data indicate that the most common mode of particle size for plutonium and uranium aerosols under a wide variety of conditions of generation is between 1 and 5 μm AD with measurable percentages of particles at 10 μm, or up to 20 μm. The appearance of particles in the inertial size range (above 1 μm AD) can be anticipated even under routine operating conditions and certainly under a wide range of accident conditions. Inlets of sampling nozzles for particulate emissions should then be tested for transmission performance in the range of 3-15 μm. The shrouded nozzle inlet, for example, is designed so that transmission of inertial size particles through the inlet is between 83% and 103% under flow conditions of intended use. Predicted performance of a design is confirmed with measurements in an aerosol wind tunnel using 10 μm AD test aerosols. The design is iterated until there is good agreement between predicted and measured performance, at which point the shrouded nozzle is qualified for use. Unless it is known that a facility stack effluent could contain a sizeable mode of very large size particles due to the nature of the materials being handled, it would not necessary to require performance testing into size ranges beyond 15 μm.

G.5 Implications for other nuclear facilities

Although the foregoing discussion has relied largely on data from plutonium facility experience, the concern for proper sampling and monitoring of large particle components of effluents downstream of HEPA filtration in other types of nuclear facilities is equally important. In their review of a wide range of literature on particle size distributions of radioactive aerosols measured in workplaces throughout the nuclear industry and government laboratories, Dorrian and Bailey (1995) found that in a total of 52 papers reporting 160 measurements of particle AMAD, the measurements of AMAD in the nuclear power industry and fuel handling facilities follow similar distributions to those in workplaces as a whole, with median values of about 4 μm. The exception seems to be uranium mills where the median is about 7 μm. Ström (1989) reviewed the characteristics of accident-generated aerosols in Swedish power reactors. A large body of literature exists on aerosols, vapors, and gases generated in postulated power reactor accidents. Little is available concerning less consequential off-normal events. The implication is clearly that the challenge aerosols presented to HEPA filtration in stacks and ducts in practically any nuclear facility will contain a significant component of particles larger than 2 to 3 μm AD, and thus could be present downstream of the filtration banks upstream of where sample extraction takes place.

Annex H
(informative)

Tritium sampling and detection

H.1 Tritium chemistry

Tritium, an isotope of hydrogen, generally behaves in a manner similar to hydrogen. Typically it is found in two primary forms in the exhaust stream: 1) in the elemental form as a gas, or 2) in the oxide form as water vapor. It is of particular interest that tritium in the oxide form has a boiling point slightly greater than 100°C. (For some regulatory analysis this would allow the oxide form to be considered a liquid instead of a gas, which would allow the use of a liquid physical form factor instead of that for a gas.)

Also, tritium is sometimes found in the exhaust stream as a component of methane or other volatile organic, or as a component of particulate matter. One such example is LiOH, where the hydrogen is replaced with a tritium molecule (LiOT). This compound is a solid material at temperatures over 400°C.

H.2 Sampling considerations

The first step in selecting an appropriate sampling system is determine the chemical form of tritium in the exhaust stream. If it is present in multiple forms, multiple sampling techniques may be employed. When the oxide form is present, the temperature and moisture content of the exhaust stream must be carefully considered. If the exhaust stream contains water in droplet form, then the tritium may also be in this form and sampling as though particles were present is recommended. Sampling for a vapor only is appropriate when the oxide is not be expected to condense.

H.2.1 Sample nozzle

The sampler nozzle should be located in the appropriate place depending on the chemical form of tritium. The location and nozzle configuration should conform to practices outlined elsewhere in this guide.

H.2.2 Heat tracing

The use of heat tracing on sample lines designed for tritium sampling should be evaluated very carefully. Several of the tritium sample collection methods rely on either absorption of water vapor into a media or condensation in a condenser apparatus. If the temperature of the sample is maintained too high, the tritium will desorb from the media, not all of the vapor will condense, and some of the absorbing solution in bubblers could be lost. All of these conditions will result in biased results.
On the other hand, if the physical state of the tritium in the exhaust is gaseous or vaporous, and the exhaust stream contains high humidity, then heat tracing may be needed to avoid condensation of sample in the sample lines and sample chamber. Condensation could cause the sample collector to plug and in the case of an ionization chamber, the reading could be disrupted because of shorting the central electrode to ground or the high voltage electrode.

H.2.3 Media location

Except for tritium existing in a particulate form, the tritium sample media is generally located downstream of a particulate filter. This keeps particles from plugging the sample media.

H.3 Sample Media

There are several generally acceptable methods and/or media available for sampling tritium when it is not in the particulate form. When it is in the particulate form, then sampling methods for particulate matter discussed elsewhere in this guide should be used.

Although there are many factors that affect the sensitivity of a method, sensitivities on the order of 1 pCi/ml are possible with sampling followed by laboratory analysis. Typical factors, but certainly not all possible factors, that can affect sensitivity are sample flowrate, temperature of sampling, pressure of sampling, analytical method, and sample media.

Often, information on the concentrations of both the oxide and elemental gas forms of tritium is desired. The uptake from tritium in the oxide form is very efficient, on the order of 99% (NCRP, 1979); however, only 0.004% of the elemental tritium entering the body is converted to the oxide form and adsorbed. Therefore, releases of tritium in the elemental form will have a much lower dose than that from the same quantity of tritium oxide. Combinations of the following methods can be used to determine total tritium and oxide levels, with the difference being the elemental tritium in the stream being sampled. Direct measurement is also possible by first removing the tritium oxide, then converting the elemental tritium to an oxide form, followed by additional sampling.

H.3.1 Silica gel

This method of sampling tritium oxide is the simplest to perform. This is a continuous sample collected over a period of days to weeks. It involves placing a canister of silica gel in the sample stream and absorbing the tritium as water vapor on the silica gel. Indicating silica gel, which is one shade of blue when fresh and either another shade of blue or a completely different color after it absorbs moisture, can be used for sampling tritium oxide. Once the sample is collected it is sent to a laboratory where it is heated to desorb the tritiated water.

If tritium in the elemental form is present, then a catalyst, such as palladium, can be installed upstream of the sample chamber. The catalyst converts the elemental tritium to the oxide form which can be absorbed on the silica gel.

H.3.2 Molecular sieves

This method is identical to the silica gel method, except molecular sieves are used in place of silica gel. This method has a two advantages over silica gel: 1) the media can be better dried initially, resulting in a lower background; and 2) a palladium catalyst, which converts the elemental tritium to the oxide form, can be coated directly on the molecular sieve. A primary drawback of molecular sieves is desorption of the tritium. This typically involves heating the media to 500°C in an evacuated furnace. Also, molecular sieves have a lower moisture handling capacity than silica gel, but the media is a more efficient drier. Therefore, when the moisture content of the sampled exhaust is high, silica gel is probably a better media. However, when the moisture content is low, molecular sieves may be a better choice.

H.3.3 Bubblers

Although a variety of absorbing materials can be used in bubblers, the most common is ethylene glycol. This method provides advantages to the laboratory, in that sample desorption is not required. The primary disadvantage is that the liquid media and bubblers are typically glass, and they must be handled in the field or plant environment.

H.3.4 Condensation

In high moisture exhaust streams, condensation may be the method of choice, since the other methods are limited by exhaustion of the absorption media; however, this method can be difficult to use. This method is based on the condensation of tritiated water with a dehumidifier or condenser. The sample is routed through a mechanical cooling system, and the condensate is collected in the liquid state. A loss or reduction of cooling capacity of the condenser will allow tritium containing moisture to leave the system in the exit gas. If the humidity of the exhaust stream is known and it is not supersaturated, then the specific activity from the sample collected can be used with the humidity data to determine total release concentration. To ensure representative sampling, regular equipment maintenance is required.

H.3.5 Catalysts

All of the above methods rely on the tritium being in a vapor form, generally water vapor. When tritium is present as an elemental gas, then it must be converted, using a catalyst, to the oxide form before it can be sampled. Although any catalyst that will convert elemental hydrogen into the water or oxide form could be used, a palladium catalyst is the most common choice.

When tritium is present as an organic chemical species, a combustion catalyst must often be used. An example is a platinum on aluminum oxide catalyst in a heated combustion chamber. The tritium in the organic compound is oxidized to HTO and collected using the methods described above.

H.4 Common on-line detection methods

H.4.1 Ionization detectors

This is a very simple detector that will detect both elemental and oxide forms of tritium. A sensitivity of 2 pCi/ml or less can be achieved, depending of the chamber volume and the exhaust stream characteristics. The major draw back to this detector is that it is sensitive to any gamma field in the general area and to any other ionization occurring in the chamber. A second chamber is sometimes used to compensate for external gamma fields by exposing the second chamber only to the field and not the exhaust stream. An additional

chamber with a silica gel or molecular sieve pretreatment is sometimes used to discriminate between oxide and elemental tritium.

This type of detector can be used when tritium is present in organic vapors, such as tritiated methane.

H.4.2 Proportional counters

This type of counter detects tritium by using a rise-time discrimination principle. Since the soft beta of tritium has a short drift time, this detector can discriminate between tritium and other radionuclides such as noble gases or other gamma emitters. The sensitivity of these instruments is on the order of 0.01 pCi/ml.

Annex I
(informative)

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1.0 PURPOSE

This procedure specifies methods for environmental air quality particulate monitoring for radionuclides in the ambient air around the perimeter of the Piñon Ridge Mill. It further specifies methods for sampling, sample handling, equipment monitoring, and maintenance, documentation, analysis, and reporting associated with these air particulate samples.

2.0 APPLICABILITY

This procedure applies to all environmental air particulate sampling associated with perimeter and outlying areas around the Mill.

3.0 OTHER DOCUMENTS

3.1 *REFERENCES*

3.1.1 Colorado Radiation Regulations, Part 4 and Part 18 Appendix A Criterion 8 (6 CCR 1007-1).

3.1.2 US Nuclear Regulatory Commission (NRC), Office of Standards Development, 1980. "Regulatory Guide 4.14, Radiological Effluent and Environmental Monitoring at Uranium Mills." Revision 1, April

3.1.2 NRC, Office of Nuclear Regulatory Research, 2007. "Regulatory Guide 4.15, Quality Assurance for Radiological Monitoring Programs (Inception through Normal Operations to License Termination) – Effluent Streams and the Environment." Revision 2, July

3.1.3 Kleinfelder, 2008. "Work Plan for Ambient Air Monitoring." Revision 1, July 18

3.2 *EXHIBITS*

Exhibit 1 – Particulate Sampler Troubleshooting and Maintenance

4.0 EQUIPMENT AND MATERIALS

4.1 *EQUIPMENT*

4.1.1 Environmental Air Sampling Logbook.

4.1.2 Total Suspended Particulate (TSP) sampler and flow controller set to operate continuously at approximately 40 to 60 standard cubic feet per minute (SCFM).

4.1.3 Clean dustproof transport container for transporting new sampler filter papers to their respective exposure locations in the field.

4.2 *MATERIALS*

4.2.1 8 inch x 10 inch glass fiber sampler filters with approximately 99.99% filtering effectiveness for 0.3 μm particles at 5 cm/sec.

4.2.2 Sample Submittal and Tracking Form or the equivalent.

APPROVALS	*Signature*	*Date*
RSO		
Plant Manager		

4.2.3 Business-size envelopes for protection and transport of control and exposed sampler filter.

5.0 RESPONSIBILITY

5.1 The Radiation Safety Officer (RSO) or the Assistant RSO is responsible for:

5.1.1 Assigning schedules to technicians for the removal and replacement of environmental air quality particulate samples.

5.1.2 Ensuring that the technician(s) assigned to remove and replace sample media are properly trained.

5.1.3 Reviewing data from the perimeter samplers, and taking any corrective actions if necessary.

5.1.4 Ensuring that necessary reports are filed with the Colorado Department of Public Health and Environment (CDPHE).

5.2 The Radiation Security Technician (RST) is responsible for:

5.2.1 Performing sampler calibration in response to requests to verify calibration.

5.2.2 Performing sampler calibration after installation of replacement sampler motors.

5.2.3 Initiating maintenance of the particulate samplers.

5.2.4 Reporting any inconsistencies or problems encountered during field activities to the RSO or Assistant RSO.

5.2.5 Making daily operational checks of all air particulate samplers.

5.2.6 Following daily operational check procedures found in the Work Plan.

5.2.7 Reporting any inconsistencies or problems encountered during field activities to the RSO or his designee.

5.2.8 Filing of all particulate sampler data and retaining the data for a minimum of 3 years (6 CCR 1007-1 4.42.1).

6.0 PREREQUISITE INFORMATION

6.1 *DEFINITIONS*

6.1.1 Air Particulate Sampler – An air sampler used to collect particulates on a filter, which can be then analyzed for air suspended constituents.

6.1.2 Control Filter – A sampler filter used to establish the background radionuclide levels in the filter.

6.1.3 Exposed Filter – An air particulate sampler filter that has collected airborne particulates during the sampling period.

6.1.4 Fixed-Location Sampler – An air sampler located at a fixed location.

6.1.5 Load – The accumulation of filtered air particulate matter collected by a particulate sampler during a sampling period or exposure.

6.2 ***SAFETY***

6.2.1 Instruments should be shut off when changing the air particulate filter.

6.2.2 Enclosed areas may contain biting or stinging insects or rattle snakes. Care should be taken prior to entry.

6.2.3 Equipment assemblage may offer pinch points. Workers should be cautious during routine maintenance activities.

6.3 ***FREQUENCY***

6.3.1 Daily – the operation of air particulate samplers will be checked and documented.

6.3.2 Weekly – Air particulate filters will be changed bi-weekly (or more frequently as may be necessary due to filter loading) throughout the year. The schedule of filter changes may be adjusted as necessary.

6.3.3 Quarterly

6.3.3.1 Each air particulate sampler will be calibrated quarterly.

6.3.3.2 Filters will be grouped by sampler location and composited quarterly for analysis.

7.0 PROCEDURES

7.1 ***PROCEDURE FOR DAILY OPERATIONAL CHECK***

7.1.1 Refer to the "Work Plan for Ambient Air Monitoring" for daily operation check procedures.

7.2 ***PROCEDURE FOR PARTICULATE AIR SAMPLER FILTER EXCHANGE***

7.2.1 Refer to the "Work Plan for Ambient Air Monitoring" for the filter exchange procedure.

7.3 ***PROCEDURE FOR QUARTERLY SAMPLE COMPOSITE PREPARATION***

7.3.1 RST determines quarterly composite closeout (ending).

7.3.2 The RST reviews the sample volume calculations and makes corrections as needed.

7.4 ***SAMPLE ANALYSIS***

7.4.1 Determine Particulate Loading.

7.4.1.1 Clean, unexposed, desiccated filter papers are pre-weighed in the laboratory prior to exposure in the field.

7.4.1.2 Exposed and desiccated filters are weighed after exposure in the field to establish the mass of particulates loaded during exposure.

7.4.1.3 Analyze the air particulate samples for:

- U-natural
- Pb-210
- Ra-226

- Th-230

7.5 ***REPORTING RESULTS***

7.5.1 Express the results in µCi/mL of air sampled.

7.6 ***RESULT REPORT REVIEW***

7.6.1 Quarterly composite analysis are reviewed and evaluated by the RSO and the Safety Committee.

7.6.2 The RSO will evaluate the radionuclide analysis for the specific sites and report this data, conclusions, and any recommendations based on statistical and trend analysis in the semiannual report to the Radiation Management Program of the Colorado Department of Public Health and Environment in accordance with the conditions set forth in the current Colorado Radioactive Materials License.

Air Particulate Sampling Procedure EV-080

Exhibit 1

Particulate Sampler Troubleshooting and Maintenance

Particulate Sampler Troubleshooting and Maintenance

I. TROUBLESHOOTING

The particulate samplers generally operate trouble free if proper maintenance is performed. The following troubleshooting guide should assist in identifying malfunctioning components if a failure occurs:

A. Motor will not operate:
   1. Check main AC source.
   2. If motor still fails to operate:
      a. Replace the motor with a calibrated motor.
      b. Deliver inoperable motor to the instrument shop for repair or replacement.

B. Sampler will not maintain desired flow rate:
   1. Contact the RSO or his designee and request that the motor be replaced immediately.

C. If the above procedures fail to return the malfunctioning component to full operation, contact the manufacturer. Detail any corrective procedures in the appropriate logbooks.

II. MAINTENANCE

Scheduled or preventative maintenance of the sampling equipment reduces downtime and remedial maintenance and greatly enhances data recovery rates. All maintenance activities must be recorded in the appropriate logbooks. The location of replacement and spare equipment and the manufacturers' specifications and operating manuals is in the Safety Department office.

A. SAMPLER MOTOR

   The sampler motor does not require brushes or other replacement parts. Maintenance consists of checking and cleaning the motor as necessary.

B. SAMPLING HEAD

   Leaks in the sampling head are experienced infrequently. The welded seams and the conditions of the guide pins on the top surface of the head should be checked initially by visual inspection. Should a defect be suspected:
   1. Assemble the sampling head to the motor.
   2. Install a filter for resistance.
   3. Apply a soap solution to the suspect problem area.
   4. Disassemble the sampling head.
   5. Examine the inside of the head for soap solution.
   6. Repair or replace the sampling head if a leak is indicated by soap solution being inside the head.

C GASKETS

   Gaskets are located on the sample filter holder, head assembly, and motor.
   1. Inspect gaskets for wear.
   2. Replace, if necessary.

D. ADDITIONAL MAINTENANCE
   1. Clean the interior roof compartment of each sampler every one to two weeks.
   2. Clean the filter support screen with a lint free cloth and alcohol every two weeks.

1.0 PURPOSE

This procedure provides guidance and instruction for the calibration of environmental air samplers using a variable resistance orifice plate calibrator or a calibration orifice with individual resistance plates.

2.0 APPLICABILITY

This procedure applies to high-volume environmental particulate air samplers used at the Piñon Ridge Mill.

3.0 OTHER DOCUMENTS

3.1 *REFERENCES*

3.1.1 Calibration & Operating Procedures for TSP and PM-10 Monitoring Equipment, Section 1.5.1, April 1990 from the Colorado Department of Public Health and Environment (CDPHE).

3.1.2 Calibration/Audit Procedures Particulate Monitoring Equipment High Volume PM10, Section No. 1.7, Oct. 1989 from the CDPHE.

3.1.3 Colorado Radiation Regulations, Part 4 (6 CCR 1007-1).

3.1.4 EPA-600/4-77-027A Test Method Section 2.2 – Reference Method for Determination of Suspended Particulates in the Atmosphere, High-Volume Method.

3.1.5 US Nuclear Regulatory Commission (NRC), Office of Standards Development, 1980. "Regulatory Guide 4.14, Radiological Effluent and Environmental Monitoring at Uranium Mills." Revision 1, April

3.1.6 NRC, Office of Nuclear Regulatory Research, 2007. "Regulatory Guide 4.15, Quality Assurance for Radiological Monitoring Programs (Inception through Normal Operations to License Termination) – Effluent Streams and the Environment." Revision 2, July

3.1.7 Kleinfelder, 2008. "Work Plan for Ambient Air Monitoring." Revision 1, July 18

4.0 EQUIPMENT AND MATERIALS

4.1 *EQUIPMENT*

4.1.1 Manometer capable of measuring 40 inches of H_2O.

4.1.2 Manometer capable of measuring 20 inches of H_2O.

4.1.3 Variable resistance orifice calibrator capable of simulating an infinite number of resistance settings, or a multiple load/resistance plate orifice calibrator.

4.1.4 Orifice Calibrator Adapter Faceplate.

4.1.5 High-volume environmental particulate air sampler.

APPROVALS	*Signature*	*Date*
RSO		
Plant Manager		

5.0 RESPONSIBILITY

5.1 The Radiation Safety Officer (RSO) or Assistant RSO is responsible for:

5.1.1 Assigning schedules to sample technician(s) for the calibration of the particulate air samplers.

5.1.2 Ensuring that the sample technician(s) assigned to calibrate the particulate samplers are trained properly and understand the procedures employed to perform the task.

5.1.3 Calibrating the air samplers.

5.2 The Radiation Security Technician (RST) is responsible for:

5.2.1 Reporting to the RSO or Assistant RSO any inconsistencies or problems encountered with the calibration of the air samplers.

5.2.2 Filing calibration forms and retaining the forms for duration of the license.

6.0 PREREQUISITE INFORMATION

6.1 *DEFINITIONS*

6.1.1 Air Particulate Sampler - An air sampler used to collect airborne particulates on a fiber filter.

6.1.2 Manometer - A device used to measure pressure differential.

6.2 *SAFETY*

6.2.1 Avoid electrical shock and inadvertent contact with moving parts.

6.2.2 Care should be taken prior to entry into enclosed areas to avoid biting or stinging insects or rattle snakes.

6.3 *FREQUENCY*

6.3.1 Particulate air samplers will be calibrated:

6.3.1.1 Quarterly.

6.3.1.2 Any time there is a motor change.

6.3.1.3 After any maintenance of the samplers.

6.3.1.4 When the sampler is suspected to be out of calibration.

7.0 PROCEDURE

7.1 Refer to “Work Plan for Ambient Air Monitoring” for the calibration procedure.

1.0 PURPOSE

This procedure specifies methods for environmental PM-10 (particulate matter less than 10 microns [μm]) monitoring at the Piñon Ridge Mill site. It further specifies methods for sampling, sample handling, equipment monitoring, and maintenance, documentation, analysis, and reporting associated with these PM-10 samples.

2.0 APPLICABILITY

This procedure applies to environmental PM-10 sampling associated with the Mill.

3.0 OTHER DOCUMENTS

3.1 *REFERENCES*

3.1.1 Colorado Radiation Regulations, Part 4 and Part 18 Appendix A Criterion 8 (6 CCR 1007-1)

3.1.3 Kleinfelder, 2008. "Work Plan for Ambient Air Monitoring." Revision 1, July 18

3.2 *EXHIBITS*

Exhibit 1 – PM-10 Field Form

Exhibit 2 – PM-10 Daily/Weekly Checklist Form

4.0 EQUIPMENT AND MATERIALS

4.1 *EQUIPMENT*

4.1.1 PM-10 Federal Reference Method (FRM) sampler

4.1.2 Environmental Air Sampling Logbook

4.1.3 Pen

4.2 *MATERIALS*

4.2.1 PM-10 Field Form

4.2.2 PM-10 Daily/Weekly Checklist Form

4.2.3 Clean sample filter and cassette in anti-static protective bag

4.2.3 Exposed filter anti-static protective bag

5.0 RESPONSIBILITY

5.1 The Radiation Safety Officer (RSO) or the Assistant RSO is responsible for:

5.1.1 Assigning schedules to technicians for the removal and replacement of environmental PM-10 sample filters.

5.1.2 Ensuring that the technician(s) assigned to remove and replace sample media are properly trained.

5.1.3 Reviewing data from the PM-10 samplers, and taking any corrective actions if necessary.

APPROVALS	*Signature*	*Date*
RSO		
Plant Manager		

5.1.4 Ensuring that necessary reports are filed with the Colorado Department of Public Health and Environment (CDPHE).

5.2 The Radiation Security Technician (RST) is responsible for:

5.2.1 Performing sampler calibration and verifications.

5.2.2 Initiating maintenance of the PM-10 samplers.

5.2.3 Reporting any inconsistencies or problems encountered during field activities to the RSO or Assistant RSO.

5.2.4 Making operational checks of all air particulate samplers.

5.2.5 Filing and retaining all particulate sampler data.

6.0 PREREQUISITE INFORMATION

6.1 *DEFINITIONS*

6.1.1 PM-10 – Particulate matter less than 10 μm

6.1.2 Clean Filter – A PM-10 sample filter and cassette which has not been exposed

6.1.3 Exposed Filter – A PM-10 sample filter and cassette, which has collected airborne particulates during the sampling period.

6.2 *SAFETY*

6.2.1 Instruments should not be running when changing the PM-10 filter.

6.2.2 Equipment assemblage may offer pinch points. Workers should be cautious during routine maintenance activities.

6.3 *FREQUENCY*

6.3.1 Daily – the operation of air particulate samplers will be checked and documented.

6.3.2 1-in-3 days – PM-10 samples will be collected every third day in accordance with the EPA Ambient Particulate Monitoring Sample Day Schedule.

6.3.3 PM-10 filters will be changed between sampling days.

6.3.4 Monthly

6.3.4.1 PM-10 sampler calibrations will be verified.

6.3.4.2 A field blank filter will be collected from one of the two samplers.

6.3.4.3 PM-10 sample filters are sent to the laboratory for analysis.

6.3.5 Quarterly – PM-10 samplers will be calibrated quarterly.

7.0 PROCEDURES

7.1 *PROCEDURE FOR DAILY OPERATIONAL CHECK*

7.1.1 Refer to the “Work Plan for Ambient Air Monitoring” for daily operation check procedures.

7.2 ***PROCEDURE FOR PM-10 SAMPLER FILTER EXCHANGE***

7.2.1 Refer to the "Work Plan for Ambient Air Monitoring" for the filter exchange procedure.

7.3 **S*AMPLE ANALYSIS***

7.3.1 The sample filters are sent to an offsite laboratory and PM-10 loading is determined by weighing the filters.

7.4 ***RESULT REPORT REVIEW***

7.4.1 PM-10 analyses are reviewed and evaluated by the RSO or Assistant RSO.

7.4.2 The RSO will evaluate the analyses and report this data, conclusions, and any recommendations based on statistical and trend analysis in the semiannual report to the Radiation Management Program of the CDPHE in accordance with the conditions set forth in the current Colorado Radioactive Materials License.

Environmental Air Particulate Sampling Procedure EV-090

Exhibit 1

PM-10 Field Form

Partisol PM_{10} FRM Field Form

Site Name: _____ Filter ID: _____

Sampler ID #: _____ Sample Run Date: _____

Sample Setup

Technician Name: _____

Sample Setup Date: _____ Current Instrument Date: _____

Sample Setup Time: _____ Current Instrument Time: _____

Current Weather Conditions: _____

Notes: _____

Sample Retrieval

Technician Name: _____

Sample Retrieval Date: _____ Current Instrument Date: _____

Sample Retrieval Time: _____ Current Instrument Time: _____

Status Code (Stat): _____ Average Temperature (AmbT Ave): _____

Total Sampling Time (Tot): _____ Average Pressure (Pres Ave): _____

Volume Sampled (Vol): _____ Flow Rate Coefficient of Variation (%CV): _____

Current Weather Conditions: _____

Notes: _____

Field Blank

Note: Field Blank information should be recorded on Field Form for Retrieved Filter.

Field Blank procedure should be performed once a month at one site.

Filter ID: _____

Current Instrument Date: _____

Current Instrument Time: _____

Notes: _____

Environmental Air Particulate Sampling Procedure EV-090

Exhibit 2

PM-10 Daily/Weekly Checklist Form

Daily - Weekly Checklist for Partisol PM_{10} Sampler

Site Name:
Sampler ID #:
Sampler Serial #:
Sample Run Date:

Filter Information

Filter #:
Sample Setup Date:
Sample Retrieval Date:

Daily Instrument Checks

Daily Instrument Checks for the Partisol PM_{10} Sampler are only required if operating the Partisol PM_{10} Sampler on a daily basis. For 1/6 day operations, these checks should be completed on the run day and also with the weekly procedures or on a volunteer basis if daily checks are more frequent.

Sampler Operation

Date							
Time							
Technician Name							

Is sampler running?	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
If No, is filter exchange required?	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
If Yes, filter exchange is required - Go To Visual Check of Sampler then proceed to Weekly Filter Exchange														
If No, filter exchange is not required, continue with visual sampler checks, then other site activities.														
If No, sampler is not running - is this a sample run day?	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
If Yes, this is a run day and sampler is not running, check instrument for power outage information & contact appropriate personnel for next steps; see contact list in site binder.														

Visual Check of Sampler

Is sampler level and securely mounted?	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
Any visible damage to sampler?	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
If Yes, the sampler is damaged, contact appropriate personnel; see contact list in site binder.														

Weekly Instrument Checks and Filter Exchange

Date: | Time: | Technician Name:

Perform Daily Check Procedure		
Filter Exchange Day?	Yes	No
Is rain catch intact?	Yes	No
Is rain catch empty?	Yes	No

→ If No, detach from sampler and empty.

If Yes --	Remove exposed filter cartridge from sampler	
	Place sample in protective bag	
	Place sample in field container	
	Record requested information from sampler on Partisol Field Form & Filter Bag Label	

If No - - Finish other site activities

Before placing clean sample filter

Is a Monthly Check scheduled?	Yes	No
If Yes - Perform Monthly Check Procedure		
If No - Continue with Filter Exchange Procedure		

Is Field Blank Scheduled?	Yes	No
If Yes - Perform Field Blank Procedure		
If No - Continue with filter exchange procedure		

Prepare for next run --	Remove new filter cartridge from field container	
	Remove filter cartridge from protective bag	
	Install filter cartridge in sampler	
	Program sampler for next run day	
	Record requested information on Partisol Field Form, Filter Bag Label, & COC	

Notes: Please note any unusual events that could influence particulate matter levels. These include forest fire smoke, high winds, local construction activity, etc.

1.0 PURPOSE

This procedure provides guidance and instruction for the calibration of environmental PM-10 (particulate matter less than 10 microns [µm]) samplers using a Streamline Pro MultiCal Instrument.

2.0 APPLICABILITY

This procedure applies to PM-10 samplers used at the Piñon Ridge Mill.

3.0 OTHER DOCUMENTS

3.1 *REFERENCES*

3.1.1 Calibration & Operating Procedures for TSP and PM-10 Monitoring Equipment, Section 1.5.1, April 1990 from the Colorado Department of Public Health and Environment (CDPHE).

3.1.2 Calibration/Audit Procedures Particulate Monitoring Equipment High Volume PM10, Section No. 1.7, Oct. 1989 from the CDPHE.

3.1.3 Colorado Radiation Regulations, Part 4 (6 CCR 1007-1).

3.1.4 US Nuclear Regulatory Commission (NRC), Office of Standards Development, 1980. "Regulatory Guide 4.14, Radiological Effluent and Environmental Monitoring at Uranium Mills." Revision 1, April.

3.1.5 Kleinfelder, 2008. "Work Plan for Ambient Air Monitoring." Revision 1, July 18.

4.0 EQUIPMENT AND MATERIALS

4.1 *EQUIPMENT*

4.1.1 Streamline Pro MultiCal Instrument with current NIST traceable certification.

4.1.2 Flow audit adapter.

4.1.3 Filter disc and cassette.

4.1.4 Solid disc and cassette.

4.1.5 PM-10 air sampler.

4.2 *MATERIALS*

4.2.1 PM-10 Verification/Calibration Form

5.0 RESPONSIBILITY

5.1 The Radiation Safety Officer (RSO) or Assistant RSO is responsible for:

5.1.1 Assigning schedules to sample technician(s) for the calibration of the PM-10 samplers.

5.1.2 Ensuring that the sample technician(s) assigned to calibrate the PM-10

samplers are trained properly and understand the procedures employed to perform the task.

5.2 The Radiation Security Technician (RST) is responsible for:

5.2.1 Calibrating the PM-10 samplers.

5.2.2 Reporting to the RSO or Assistant RSO any inconsistencies or problems encountered with the calibration of the PM-10 samplers.

5.2.3 Filing calibration forms and retaining the forms for a minimum of 3 years (6 CCR 1007-1 4.42.1).

6.0 PREREQUISITE INFORMATION

6.1 *DEFINITIONS*

6.1.1 PM-10 – Particulate matter less than 10 microns (micrometers, μm).

6.1.2 PM-10 Sampler – An air sampler used to collect PM-10.

6.1.3 Streamline Pro MultiCal Instrument – An NIST traceable calibration standard device designed for use with the PM-10 sampler.

6.2 *SAFETY*

6.2.1 Avoid electrical shock and inadvertent contact with moving parts.

6.3 *FREQUENCY*

6.3.1 Particulate air samplers will be calibrated:

6.3.1.1 Quarterly.

6.3.1.2 Any time there is a part repair or replacement.

6.3.1.3 When the sampler is suspected to be out of calibration.

7.0 PROCEDURE

7.1 Refer to “Work Plan for Ambient Air Monitoring” for the calibration procedure.

1.0 PURPOSE

This procedure describes the methods utilized for collection, analysis, and reporting of environmental air concentrations of Radon-222 in and around the Piñon Ridge Mill.

2.0 APPLICABILITY

This procedure applies to all environmental samples of Radon-222 taken at outlying locations from the Mill.

3.0 OTHER DOCUMENTS

3.1 *REFERENCES*

3.1.1 US Nuclear Regulatory Commission (NRC), Office of Standards Development, 1980. "Regulatory Guide 4.14, Radiological Effluent and Environmental Monitoring at Uranium Mills." Revision 1, April

3.1.2 Instruction brochure for Type DRNF Outdoor Air Radon Detector, Landauer Inc. Form number 136-031.

3.2 *EXHIBITS*

Exhibit 1 – Landauer Inc. Radon Test Detector Log (Throughout this procedure "Landauer" means Landauer or its equivalent).

4.0 MATERIALS

4.1 Current Landauer Inc. Radon Test Detector Log

4.2 Landauer Type X9 Radon Detector

5.0 RESPONSIBILITY

5.1 The Radiation Safety Officer (RSO) is responsible for:

5.1.1 Ensuring that the sample technician(s) are properly trained.

5.1.2 Ensuring that data results are validated and entered into the Quarterly Radon Monitoring Report.

5.1.3 Ensuring that necessary reports are filed with the Colorado Department of Public Health and Environment (CDPHE).

5.2 The Radiation Security Technician (RST) is responsible for:

5.2.1 Receiving the Landauer Type DRNF radon detector, and checking the accuracy of the Detector Log with the detector serial numbers.

5.2.2 Following operating procedures for specific equipment being used.

5.2.3 Ensuring that detectors are intact and undamaged.

5.2.4 Following procedures for sample labeling, chain of custody and Landauer Radon Test Detector Log.

5.2.5 Shipping the radon detectors to Landauer for analysis and archiving the duplicate sheet.

APPROVALS	*Signature*	*Date*
RSO		
Plant Manager		

6.0 PREREQUISITE INFORMATION

6.1 *DEFINITIONS*

6.1.1 Landauer Inc. Radon Test Detector Log (Detector Log) – Log sheet used for initiating, tracking and documenting all radon samples.

6.2 *SAFETY*

6.2.1 Standard worker safety and handling of equipment should be observed when using this procedure.

6.3 *FREQUENCY*

6.3.1 Unexposed Radon-222 monitors will replace exposed Radon-222 monitors on a quarterly basis or as determined by the RSO.

7.0 PROCEDURE

7.1 The sample technician will receive and inspect unexposed Type DRNF outdoor air radon detectors from Landauer Inc. The detectors will be checked with regard to detector serial number accuracy, comparing the serial number on the detector with that of the Landauer supplied Radon Test Detector Log. The log provides specific identification numbers associated with each individual detector. In addition, the RST will provide the previous quarter's Landauer Radon Test Detector Log in order that detector change-out can be properly documented at the time of detector retrieval.

7.2 At one location, the RST is to place a duplicate detector and record the location in the field notebook.

7.3 After arriving at the specified sample location, the RST will:

7.3.1 Remove exposed Type DRNF detector from detector canister.

7.3.2 Place foil seal over detector openings.

7.3.3 Fill out pertinent data on the Landauer Radon Test Detector Log.

7.3.4 Remove the foil seal of unexposed detector.

7.3.5 Place unexposed filter in detector canister.

7.3.6 Fill out pertinent data on the Landauer Radon Test Detector Log.

7.4 The RST will ship the exposed radiation detector to Landauer for analysis.

7.5 Upon receipt from Landauer, the RSO will review the analytical results for any values that may exceed historical measurement. The RSO and RST will investigate possible cause(s) of elevated readings and advise the Plant Manager of potential need to implement corrective action.

Radon-222 Air Surveys Procedure EV-100

Exhibit 1

Landauer Radon Test Detector Log

Landauer Radon Test Detector Log

RADON TEST DETECTOR LOG

Company _____
Address _____
_____
_____
Phone _____
Contact _____
Account # _____

Landauer, Inc.
2 Science Road
Glenwood, IL 60425-1586

Detector Number	Starting Date			Ending Date			Detector Location/Comments
	Mo	Day	Yr	Mo	Day	Yr	

Return original copy with detectors. Retain copy for your records.

Page _____ of _____

1.0 PURPOSE

The purpose of this procedure is to measure the Radon-222 emanation rates (flux) at the Piñon Ridge Mill to demonstrate compliance with the Federal requirements at 40 CFR, Part 61, Subpart W, National Emission Standards for Radon Emissions from Operating Mill Tailings (NESHAPs) and CDPHE requirements (6 CCR 1007-1, Part 18, Appendix A). The methods described herein are consistent with EPA Method 115, per 40 Code of Federal Regulations (C.F.R.), Part 61, Environmental Protection Agency, National Emission Standards for Hazardous Air Pollutants: Radionuclides; Final Rule and Notice of Reconsideration, December 15, 1989.

2.0 APPLICABILITY

This procedure applies to the collection of radon flux samples and the measurement of the radon emanation rate from the Mill tailing cells.

3.0 OTHER DOCUMENTS

3.1 *REFERENCES*

3.1.1 USEPA, National Emission Standards for Radon Emissions from Operating Mill Tailings (NESHAPs), 40 CFR 61, Subpart W

3.1.2 Colorado Department of Public Health and Environment, *Criteria Relating to the Operation of Mills and the Disposition of the Tailings or Wastes from these Operations*, 6 CCR 1007-1, Part 18, Appendix A.

3.1.3 USEPA Method 115, 40 CFR 61, December 15, 1989

3.2 *EXHIBITS*

Exhibit 1 – GPS Location Worksheet

4.0 EQUIPMENT AND MATERIALS

4.1 *EQUIPMENT*

4.1.1 Global Positioning System (GPS) unit, or equivalent.

4.1.2 Shovel.

4.1.3 Funnel apparatus.

4.1.4 Rain gauge.

4.1.5 High/low temperature recording thermometer.

4.1.6 Awl.

4.1.7 105 large area canister-type radon flux collectors.

4.2 *MATERIALS*

4.2.1 Black electrical tape.

4.2.2 212 containers of unexposed specification charcoal.

APPROVALS	*Signature*	*Date*
RSO		
Plant Manager		

5.0 RESPONSIBILITY

5.1 The RSO or designee is responsible for:

5.1.1 Ordering the canisters for the current test year.

5.1.2 Scheduling of the Radon Flux Measurement effort.

5.1.3 Follow up report review, data analysis and report finalization interface with the laboratory.

5.2 The Radiation Security Technician (RST) is responsible for:

5.2.1 Obtaining precipitation and temperature readings for the Mill site (see Procedure EV-130).

5.2.2 Filling the radon flux collectors with charcoal upon receipt.

5.2.3 Deploying the canisters, ensuring canisters are evenly dispersed.

5.2.4 Documenting deployment times and GPS locations.

5.2.5 Retrieving the canisters.

5.2.6 Documenting the canister retrieval time.

5.2.7 Emptying the exposed canisters into a labeled sample container and sealing the container.

5.2.8 Prompt shipping of the containerized charcoal to the laboratory for analysis.

5.2.9 Decontamination and survey of all equipment.

5.2.10 Shipment of equipment back to the laboratory.

5.2.11 Designating reference locations for the aerial photography.

5.3 The laboratory is responsible for:

5.3.1 Analysis of the exposed charcoal.

5.3.2 Estimating location specific radon emanation.

5.3.3 Providing Quality Assurance/Quality Control information.

5.3.4 Finalizing the written report to Colorado Department of Public Health and Environment's Air Pollution Control Division (APCD).

6.0 PREREQUISITE INFORMATION

6.1 ***SAFETY***

6.1.1 Safety glasses.

6.1.2 Rubber boots are to be worn during tailings beach activities.

6.1.3 Breathing zone sampler to be worn during tailings beach activities.

6.2 ***FREQUENCY***

6.2.1 Radon Flux measurement testing is performed during the late spring or summer when meteorological conditions are best suited for testing. Ground must be dry and completely thawed and air temperature should be moderate.

6.2.2 In accordance with the Method requirements, testing is conducted when ambient air temperatures are above 35 degrees F, and at least 24 hours after measurable precipitation.

6.2.3 The duration of testing is a maximum of four (4) days.

7.0 PROCEDURES

7.1 *ROUTINE PROCEDURE*

7.1.1 Canister Deployment

A three-man crew is generally utilized during the Radon Flux testing effort. The sampling is provided with oversight from an RST, who may also participate in the test procedure. Radon Flux testing usually lasts four (4) full days and preferably begins on a Monday in order to accommodate the time necessary to complete the test program. Radon Flux canisters (Large Area Activated Charcoal Canisters – LAACC) are filled with a 180-gram "charge" of unexposed charcoal which is evenly distributed across the canister's charcoal support grid. The collector is then re-assembled and set aside upside down. NOTE: Care must be taken to keep the canisters in the upside-down position at all times as to eliminate any chance for charcoal spillage.

7.1.1.1 Charged canisters are transferred to the test location by means of vehicle transport in batches of 20 or 30 canisters. The transfer process is ongoing until all canisters are deployed.

7.1.1.2 Each of the two testing rounds consists of the deployed canisters and additional field control canisters which are placed in a sealed plastic bag and set aside at a rate of 1 for every 20 deployed canisters.

7.1.1.3 One-half of the test canisters will be deployed to the exposed tailings beach(s) and the remainder distributed over the soil-covered beach region(s).

7.1.1.4 The deployment of the canisters begins at a convenient location, whether on the tailings beach, the soil-covered tailings area or other chosen location. The canisters are evenly distributed over the test areas. Each canister is carefully placed on the ground where dirt is banked around the canister and at its base to form a containment seal; a location label is placed on the canister; and a pin flag is marked with the location ID and placed beside the canister.

NOTE: A break in the sequential numbering of the canisters during retrieval is utilized to identify any missed canisters.

7.1.1.5 Two colors of pin flags are used during the test, one for the tailings beach and one for soil-covered areas. The two-color

system is used to assure proper area segregation of collected canisters and proper assignment to the per-designated numerical system.

7.1.1.6 As the canisters are deployed, the deployment time and location coordinates indicated by a hand-held GPS instrument are recorded. These coordinates are used later to plot the canister locations on a digital map and/or to find specific test locations after test results become available.

7.1.2 Canister Retrieval

7.1.2.1 On Day 2 of the Radon Flux test, the round one canisters are collected, but only after the required 24-hour exposure period is complete.

7.1.2.2 At retrieval, the load batch information and the retrieval time are recorded for each load batch. The time between retrieval and transferring the exposed charcoal should be held to a minimum; however, site and field conditions contribute to the timelines of the transfer.

7.1.2.3 Retrieved canisters are returned to the initial canister assembly station and prepared for shipment. At the station, each canister is disassembled and the charcoal is collected into sealed containers, which are appropriately labeled to identify the sample location.

7.1.2.4 The activated charcoal is removed from the collector by removing the remaining rod and pad from the collector and dumping the charcoal into a large funnel which empties into the pre-number steel alloy cap. The can's lid is placed and a wrap of electrical tape is applied to the can seam to eliminate any charcoal loss due to lid removal or introduction of air and/or radon into the can. NOTE: Great care must be taken to avoid spillage, to preserve the charcoal during charcoal transfer and ensure a complete seal.

7.1.2.4 Second round deployment and testing are conducted on Days 3 and 4 and follow the same procedural sequence described above for the first round activity.

7.1.3 Canister Decontamination

7.1.3.1 Emptied canisters are transported to the Mill, where they are scrubbed with a brush and fresh water.

7.1.3.1.1 After the canisters have sufficiently dried, an alpha survey for total activity is performed on at least 10% of the canisters. Canisters are released based on prescribed limits for equipment release, as established in Radiation Protection Procedure RH-070.

7.1.3.1.2 The exposed charcoal containers, canisters and associated equipment are then boxed and shipped back to the laboratory by means of the earliest available over-night delivery service.

Radon Flux Measurements Procedure EV-110

Exhibit 1

GPS Location Worksheet

GPS Location Worksheet

GPS Radon Canister Locations

Date:_____ Area: _____

Technician:_____

Loc #	North	West
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
19		
20		
21		
22		
23		
24		
25		

Loc #	North	West
26		
27		
28		
29		
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32		
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39		
40		
41		
42		
43		
44		
45		
46		
47		
48		
49		
50		

Loc #	North	West
51		
52		
53		
54		
55		
56		
57		
58		
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60		
61		
62		
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72		
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74		
75		

Loc #	North	West
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1.0 PURPOSE

The purpose of this procedure is to determine gamma radiation levels in the environment around the Piñon Ridge Mill using dosimetry.

2.0 APPLICABILITY

This procedure applies to all Thermoluminescent Dosimeters (TLD) and/or Optically Stimulated Luminescent Dosimeters (OSL) distributed in the environment around the Mill.

3.0 MATERIALS

3.1 *MATERIALS*

3.1.1 TLD or OSL dosimetry badges.

3.1.2 6” x 6” ziplock bags or equivalent.

3.1.3 Field notebook.

4.0 RESPONSIBILITY

4.1 The Radiation Safety Officer (RSO) is responsible for:

4.1.1 Ensuring that the Radiation Security Technicians (RST) are placing the TLDs/OSLs according to proper procedures and that these procedures are followed.

4.1.2 Ensuring the sample technicians are properly trained in placement and exchange of the TLDs/OSLs.

4.1.3 Determining the schedule of TLD/OSL retrieval and replacement.

4.1.4 Reviewing analysis of the TLD/OSL results to determine if any corrective actions need to be taken.

4.2 The RST is responsible for:

4.2.1 Having all necessary materials and supplies before going to the TLD/OSL sample stations for retrieval and replacement.

4.2.2 Advising the RSO of any deviations from the planned activities or problems encountered during sample TLD/OSL recovery or installation that may affect analysis results.

4.2.3 Ordering unexposed TLDs/OSLs to replace exposed TLDs/OSLs for all environmental sample locations, one duplicate TLD/OSL and one control TLD/OSL.

4.2.4 Processing and sending exposed TLDs/OSLs for analysis to approved vendor.

APPROVALS	*Signature*	*Date*
RSO		
Plant Manager		

5.0 PREREQUISITE INFORMATION

5.1 *DEFINITIONS*

5.1.1 Thermoluminescent Dosimetry Badges (TLDs) and/or Optically Stimulated Luminescent Dosimeters (OSLs) – A dosimeter that provides accumulated exposure to X and gamma rays. Environmental dosimeter models will be used for this procedure.

5.2 *FREQUENCY*

5.2.1 Exchange TLDs/OSLs quarterly.

6.0 PROCEDURE

6.1 The RSO will produce a schedule for the replacement and collection of TLDs/OSLs. This procedure should be repeated quarterly unless otherwise directed by the RSO.

6.2 The RST will order TLDs/OSLs specific for the environmental dosimetry program.

6.3 After receiving the TLDs/OSLs, the RST will send the transit control TLD/OSL back to the lab for analysis.

6.4 A second control badge should be received with each unexposed shipment. This control should be stored in a secure background office location (no potential for exposure to radioactive materials in the mill) during each deployment period and returned to the vendor with the exposed badges.

6.5 The RST will place the TLDs/OSLs in a ziplock bag, and upon arrival at the sampling location, place the TLD/OSL in locations that are protected against being eaten by cattle and protected against extremes in temperature and physical damage. The time, date, location, TLD/OSL identification number and the RST's name are to be recorded in the field notebook.

6.6 The RST will continue to all remaining sampling location and exchange the TLDs/OSLs.

6.7 At one location, the RST is to place a duplicate TLD/OSL and record the location in the field notebook.

6.8 The RST will fill out all necessary information on the exchange form from the TLD/OSL vender and ship the TLDs/OSLs back to the vender for processing.

6.9 Upon receipt of the TLD/OSL measured radiation doses from the processing facility the RSO will evaluate the exposure levels for the specific sites and report this data, conclusions and any recommendations based on statistical and trend analysis in the semiannual report to the Plant Manager and to the Colorado Department of Health and Environment (CDPHE).

1.0 PURPOSE

This procedure provides the methods to calculate doses to off-site members of the public for planning or compliance purposes using the MILDOS computer code.

2.0 APPLICABILITY

This procedure applies to all modeling calculations made to estimate doses to members of the public resulting from effluents from the Piñon Ridge Mill.

3.0 OTHER DOCUMENTS

3.1 *REFERENCES*

3.1.1 Argonne National Laboratory, MILDOS-Area User's Guide (Draft), Environmental Assessment Division, September 1998.

3.1.2 USNRC Regulatory Guide 3.59, Methods for Estimating Radioactive and Toxic Airborne Source Terms for Uranium Milling Operations.

3.1.3 Yuan, Y.C., J.H.C. Wang, and A. Zielen, MILDOS-AREA: An Enhanced Version of Mildos for Large Area Sources. Argonne National Laboratory Report ANL/ES-161, June 1989.

3.1.4 Colorado Radiation Control Regulations (6 CCR 1007-1), Part 4 *Standards for Protection Against Radiation* and Part 18, Appendix A – *Criteria Relating to the Operation of Mills and the Disposition of the Tailings or Wastes From these Operations.*

4.0 EQUIPMENT AND MATERIALS

4.1 *EQUIPMENT*

4.1.1 Personal computer with the referenced version of MILDOS software installed.

5.0 RESPONSIBILITY

5.1 The Radiation Safety Officer (RSO) or the Assistant RSO is responsible for:

5.1.1 Ensuring that the dose calculations are performed annually or as determined by the RSO.

5.1.2 Ensuring that the sampling of area sources and point sources are conducted as described in other applicable EV procedures.

5.1.3 Reviewing the environmental dose calculations for entry into the Annual Report.

5.1.4 Ensuring that meteorological data is available for the dose calculations.

5.1.5 Filing and retaining the Annual Report for at least 3 years.

APPROVALS	*Signature*	*Date*
RSO		
Plant Manager		

6.0 PREREQUISITE INFORMATION

6.1 *DEFINITIONS*

6.1.1 Point source - A release point of small aerial extent, such as a stack.

6.1.2 Area source - A quadrilateral release point of larger aerial extent, such as an ore pile or tailings cell as defined by four corner points.

6.1.3 Release rate - A point source release in units of Ci/yr.

6.1.4 Nuclide mix - A mix of radionuclides used with area (quadrilateral) sources to define releases, in units of pCi/g of material.

6.2 *FREQUENCY*

6.2.1 Annually assess the off-site radiation dose from the Mill and as needed.

7.0 PROCEDURES

7.1 MILDOS Assessment of Radiation Doses attributed to the Mill. According to Argonne National Laboratory, "MILDOS software is used by the U.S. Nuclear Regulatory Commission (NRC) to estimate radiological doses and risks from uranium milling licensing activities". More importantly, Argonne's program "calculates the radiation doses received by individuals and the general population within an 80-km radius of an operating **uranium recovery facility**" (emphasis added). The MILDOS code calculates the radiation doses at specified receptor locations.

7.1.1 Define point source terms as defined in Yuan (1989) and Argonne National Laboratory (1998).

7.1.1.1 Each point source must be entered as an (x, y, z) array relative to the base of the yellowcake stack.

7.1.1.2 Release rates for each point source must be entered in terms of Ci/y as measured by stack sampling, by applying material-specific activities to estimate particulate emissions derived from the Mill Emissions Permit or as otherwise specified by USNRC Regulatory Guide 3.59. When it is known that the uranium decay series is in equilibrium, equilibrium values will be entered automatically within the program.

7.1.1.3 If the decay chain is not in equilibrium, appropriate release rates for nuclides of interest within the chain must be entered.

7.1.1.4 Enter appropriate solubility class for each point source release.

7.1.2 Define area (quadrilateral) source terms as defined in Yuan (1989) and Argonne National Laboratory (1998).

7.1.2.1 Each area source must be defined by four points expressed: x, y coordinates. An elevation coordinate (z) is also defined at the center of the quadrilateral, expressed in meters relative to the base of the yellowcake stack.

7.1.2.2 For each radionuclide, enter the appropriate activity concentrations in pCi/g. When it is known that the uranium decay series is in equilibrium, equilibrium values will be entered automatically within the program.

7.1.2.3 If the decay chain is not in equilibrium, appropriate activities for nuclides of interest within the chain must be entered as concentrations.

7.1.2.4 Choose the appropriate nuclide mix and particle size to represent the material matrix being considered for each area source. Area source activities are determined by area sampling/analysis or on the basis of known activities of materials in storage (e.g. ore grade information etc.). Particle sizes are derived from USNRC Regulatory Guide 3.59 or the program default.

7.1.3 Define up to 48 appropriate receptor points.

7.1.3.1 Each receptor point is defined by an (x, y, z) array relative to the base of the yellowcake stack.

7.1.4 Enter appropriate atmospheric data.

7.1.4.1 Wind data obtained from Mill on-site meteorological monitoring station (EV-130) must be entered in a stability array (STAR) format and read into the model.

7.1.5 Enter pertinent time step parameters.

7.1.6 Population data are not entered as a collective dose projection and are not required for annual reporting purposes.

7.1.7 Enter appropriate food pathway parameters.

7.1.7.1 The milk pathway is not used for the Mill because milk usage from local dairies is minimal and results in a negligible dose.

7.1.8 Choose desired print out format. Enter an output report title, if desired.

7.1.9 Save the data file with a unique name.

7.1.9.1 Input data files have a “rad” filename extension.

7.1.10 Run the model.

7.1.11 Examine model output, initially labeled “mildos.rep” to select doses to receptors of interest.

7.1.12 Repeat 7.1.1 through 7.1.11 as necessary to model all required release points and materials.

7.1.13 Collate results for uranium decay chain radionuclides.

7.2 Provide the results of the MILDOS off-site dose calculations to the RSO who enters the data and any assessments into the Annual Report for submission to the Colorado Department of Public Health and Environment. File and retain the MILDOS assessment until license is terminated or longer.