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October 18, 2016

Via Electronic Mail

Ms. Andrea Kock, Deputy Director
Decommissioning and Uranium Recovery Licensing Directorate
Division of Waste Management and Environmental Protection
Office of Federal and State Materials and Environmental Management Programs
U.S. Nuclear Regulatory Commission
11545 Rockville Pike
Rockville, MD 20852-2738

Dear Ms. Kock:

Subject: **Sweetwater Uranium Project – Docket Number: 40-8584**
Source Material License SUA-1350 - Sweetwater County, Wyoming – Completion of the Response to the August 25, 2016 Letter - Attachment 2 - Groundwater Monitoring Plan and Attachment 3 - Air Effluent Monitoring Program

The U.S. Nuclear Regulatory Commission (NRC) is conducting a review of the Kennecott Uranium Company (Kennecott) Sweetwater Uranium Project request for a ten-year renewal of Source Material License SUA-1350 that was submitted on July 24, 2014. The NRC provided Requests for Additional Information (RAIs) in letters dated July 13, 2015 and February 12, 2016. On August 18, 2016, a public conference call involving Kennecott and the agency was held to discuss specific license conditions that will be modified as part of the license renewal process. A letter dated August 25, 2016 entitled *Draft Renewal Materials License, Sweetwater Uranium Project; Sweetwater County, Wyoming* was received following the conference call. This letter contained draft language for License Conditions 9.10, 11.3 and 11.4. In partial response to this letter, specifically to the item entitled License Condition 11.3, Kennecott provided a letter dated September 1, 2016 that committed to provide a characterization plan for the groundwater plume by Friday, September 16, 2016 for agency review. In addition, a revised site air monitoring station location map was submitted.

To complete the response to the August 25, 2016 letter, Kennecott Uranium Company is providing two (2) additional documents which are as follows:

- Attachment 2 - Groundwater Monitoring Plan
  - This document provides the requested information regarding groundwater monitoring related to the first new tailings impoundment and new evaporation ponds.
- Attachment 3 - Air Effluent Monitoring Program
  - This document provides the requested information regarding the operational stack and airborne effluent monitoring plan for the facility

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Kennecott Uranium Company apologizes for the delay in providing these two (2) submittals. Their preparation required more time than was originally estimated.

If you have any questions please do not hesitate to contact me.

Sincerely yours,

Oscar A Paulson

Oscar Paulson
Facility Supervisor

Cc: James Webb – Project Manager – (2)
Director – USNRC DNMS – Region IV (w/o enc.)
Rich Atkinson

ATTACHMENT 2

Responses to NRC Letter Dated August 25, 2016
Sweetwater Uranium Facility, Docket Number: 40-8584
Source Material License SUA-1350
License Condition 11.4, Groundwater Monitoring

The U.S. Nuclear Regulatory Commission (NRC) is reviewing Kennecott Uranium Company's (Kennecott's) Sweetwater Uranium Project request for a ten-year renewal of Source Material License SUA-1350 that was submitted on July 24, 2014. The NRC provided Requests for Additional Information (RAIs) in letters dated July 13, 2015 and February 12, 2016. On August 18, 2016, a public conference call was held to discuss specific license conditions that will be modified as part of the license renewal process. This letter provides a response to the NRC's request by conference call and follow-up letter dated August 25, 2016 to further address the groundwater monitoring program for the first new tailings impoundment and proposed evaporation ponds. Specifically, it was requested that a monitoring program should be developed to detect leakage in the unlikely event of tailings fluid leaking through all three liner layers from the first newly constructed impoundment even though the first new impoundment is proposed to be located above existing mill-impacted groundwater (License Condition 11.4, Part 1).

BACKGROUND

Plume History

In spring 1983, a leak developed in the upper portion of the single-layer synthetic liner of the tailings impoundment while the site was managed by the previous licensee, Minerals Exploration Company (MEC), a wholly owned subsidiary of Union Oil of California (UNOCAL), allowing tailings water to seep downward into the underlying geologic materials. The surface of the saturated Battle Spring Aquifer is located approximately 100 to 110 feet below ground surface near the existing tailings impoundment. A discontinuous sandstone lens is located generally below the existing tailings impoundment. Leaked fluids perched above this sandstone lens and ultimately migrated downward into the upper saturated fifty (50) feet of the Battle Spring Aquifer. Evaporation was allowed to lower the water level in the impoundment to below the elevation of the damaged liner. No additional fluid was added to the impoundment from the time of cessation of operations (spring 1983) until spring 1986, allowing fluid levels to decrease via evaporation. Since 1986, the licensee has operated an enhanced evaporation system in the tailings impoundment consisting at various times and as conditions warranted of a spray system, liner drip system, and/or flooded evaporation lagoons to decrease fluid volumes in the impoundment and evaporate contaminated groundwater pumped back into the impoundment.

A Corrective Action Program (CAP) was implemented with the objective of returning the groundwater concentrations of chromium, U-Nat, and Ra 226-228 in areas that were

impacted by mill process fluids to below corrective action levels. The license further stipulates that the groundwater protection standards apply to point of compliance (POC) wells TMWs 15, 16, 17, and 18, which are located near the perimeter of the existing tailings impoundment. A groundwater pumping program north and west of the tailings impoundment was initiated in 1986 to recover affected groundwater and the associated contamination in the Battle Spring Aquifer. Using stipulated and optional wells, the pumping program has continued to the present time. The pumped groundwater is discharged to the tailings impoundment for subsequent storage and evaporation.

Additionally, groundwater with elevated uranium and potentially affected by organic compounds was identified in the catchment basin area, leading to the installation of additional wells to characterize the extent of impact therefrom. Groundwater pumping adjacent to the catchment basin from TMWs 96 and 97 was initiated in 2005 to recover the impacted groundwater and reduce the potential for offsite migration. In addition, in 2006 and 2007 the soil contamination (source term) associated with the catchment basin was excavated and placed in the tailing impoundment. Pumping continues to the present and the extracted groundwater is also discharged to the tailings impoundment for evaporation.

The first new tailings impoundment allowed under the facility license is proposed to be located 100 feet due north of the existing impoundment, and the evaporation ponds to the south of the existing impoundment (see Figure 1). Figure 1 also shows the locations of monitoring wells and the approximate location of the historical extent of perched water above the discontinuous sandstone lens.

Rationale for the Proposed Impoundment Location

The first proposed tailings impoundment and evaporation ponds will be located generally over a portion of the plume created by historical leaks from the tailings impoundment. Figure 2 shows the approximate footprints of these impoundments, and also monitoring wells, 2015 groundwater contours, and a depiction of the plume(s) as defined by sulfate concentrations.

The design location for the first new tailings impoundment was selected to minimize the footprint of area affected by mill operations. Kennecott considers the footprint of the area impacted by mill operations to be not only those areas impacted by surface disturbance but those areas underlain by impacted groundwater. A more distant location from the existing impoundment would create two distinct and separate tailings storage areas. Kennecott preferred a more consolidated footprint. Similarly, a location for the evaporation ponds near the mill and existing impoundment, to also consolidate the affected footprint, was preferred. The above is true even though a close-in (small-footprint) location for these facilities will locate them at least partially over the plume.

The primary operational rationale for proposing the location of new tailings impoundments close to the existing impoundment is proximity to the mill to limit the length of tailings pipeline. A more distant location would require a longer tailings delivery line and greater

potential for leakage, line breaks and other failures therefrom, especially in cold weather. Longer tailings lines also have a greater potential for plugging (sanding up). Two tailings lines will be installed with one being a backup line to be used in the event of plugging or other problems with the primary line. The pipelines will be equipped with rupture detector alarms that will alert the operator in the mill to switch flow to the second/backup tailings line in the event of a rupture of the primary line. This is discussed in Final Design Volume VII Section 4 – Tailings Management Plan (Shepherd Miller, Inc., 1997b).

The more protective location for the tailings impoundments against unexpected impacts to local water resources, from either 1) the unlikely event of tailings fluid leaking through all three liner layers or 2) from tailings line ruptures, is to place them as close as reasonably possible to the mill and to the existing impoundment.

Liner Design

The liner design, detailed in the Final Design Volume IV (Shepherd Miller, Inc., 1997a), and incorporated into the facility's performance-based operating license, includes a process water recovery system (PWRS) to limit head over the liner system, with recovered water pumped either to evaporation ponds or recycled to the mill for reuse. The PWRS provides an important first level of protection against potential leakage by minimizing the hydraulic head over the liner system, and thus decreasing the potential for a leak to release a relatively large volume of water.

The liner system includes three barriers to downward movement of tailings fluid:

- An upper 60 mil geosynthetic high density polyethylene liner
- A lower 40 mil geosynthetic high density polyethylene liner
- A three-foot thick clay layer, with a field permeability equal to or less than 1 x 10^{-7} cm/sec.

The top pair of liners will be separated by a leak detection and recovery system (LDRS). The LDRS will drain to a sump in the lowest corner of the impoundment from which collected fluids can be pumped. The lower 40-mil liner will be overlain immediately above the three-foot clay liner to create a composite lower liner. The underlying clay layer will provide both restriction to flow due to low permeability, but also chemical attenuation capacity for positively charged ions (e.g., uranium, radium).

A double-lined system for the evaporation pond system, with eight to ten cells, was also designed and incorporated into the facility's license, including:

- An upper 60 mil geosynthetic high density polyethylene liner
- A lower 60 mil geosynthetic high density polyethylene liner, separated by an LDRS.

The LDRS in each evaporation cell will drain to a sump in the lowest corner of each cell from which collected fluids can be pumped.

LEAK DETECTION AND EARLY WARNING

Kennecott proposes a four-tiered approach to leak detection and groundwater monitoring for the first new tailings impoundment, with a similar approach to be applied to additional tailings impoundments as each is constructed and placed into operation, as applicable:

1. Injection of a potassium bromide tracer into the tailings stream
2. Monitoring of the LDRS
3. Groundwater monitoring of the zone above the clay aquitard located near the southwest corner of the first new tailings impoundment
4. Groundwater monitoring of the Battle Spring Aquifer, south and southwest of the impoundment.

Kennecott proposes a three-tiered approach to leak detection and groundwater monitoring for the evaporation ponds:

1. Injection of a potassium bromide tracer into the tailings stream
2. Monitoring of the LDRS
3. Groundwater monitoring of the Battle Spring Aquifer, south, west and north of the evaporation ponds.

Tracer

The use of a tracer as a part of groundwater monitoring was not included in the Final Design or incorporated into the facility's performance-based license, but is proposed now in this document. A potassium bromide solution will be injected into the tailings discharge line prior to its discharge at the impoundment. Bromide is not found in either mill process fluids or in background groundwater, is chemically stable, has low toxicity, moves readily with water it is mixed into, is not easily filtered or sorbed by the tailings or underlying soil/rock strata, and is easily detected in water samples. Thus, the presence of bromide in any water sample would be an indicator that the water being sampled has been impacted by mill processes. Kennecott will test for bromide in groundwater samples either with a bromide probe or through laboratory analysis.

LDRS Monitoring

The monitoring of fluid levels in the LDRS for both the tailings impoundments and evaporation ponds will provide the first warning of a potential leak, and of the need to determine if action is necessary to modify the water management plan for the tailings impoundment or evaporation ponds. Upon commencement of tailings impoundment and evaporation ponds operations, Kennecott will monitor each impoundment's sump as part of the routine monitoring program. The significance of water detected in the LDRS sump would be determined through measurement of the fluid quantity. Shepherd Miller, Inc. (1997b), in the Final Design Volume VII, calculated three potential leakage rates, for both tailings impoundments and evaporation ponds:

1. A de minimis, or minimum expected quantity of fluid seepage
2. A design-level leakage rate
3. An action leakage rate (ALR) between the de minimis and design-level leakage rate.

A determination that the ALR has occurred would trigger action by Kennecott to: 1) provide notice to the NRC, 2) actively pump from the LDRS, and 3) institute daily monitoring of LDRS fluid levels. The objective of these responses to a detected ALR would be to minimize head over the lower liner and reduce the potential for leakage.

Perched Aquifer Monitoring/Tailings Impoundment

Twenty-five wells were completed in the perched aquifer soon after the 1983 leak was detected. The perched aquifer was located beneath the northern portion of the existing tailings impoundment, and extended northward for approximately 1,000 feet (Figure 1). The perched aquifer was created as tailings fluid collected in a sandstone zone above a discontinuous clay lens that acted as an aquitard. Figure 3 presents a geologic cross section (Shepherd Miller, 1995) created from exploration borehole logs and monitoring well logs. Figure 3 depicts the location of the perched aquifer and the various sandstone strata which characterize the local sedimentary geology.

The perched zone wells were pumped by the previous licensee to remove tailings fluid that collected above the clay lens/aquitard beneath the existing impoundment. This aquitard and the wells completed in the currently unsaturated zone above it provide an additional opportunity for monitoring of the unlikely potential fluids escaping the LDRS and lower synthetic liner, migrating through the clay liner, and seeping to the perched zone. Kennecott proposes that TMW-65, completed to a depth of 78 feet below ground surface, be used as the monitoring well to detect fluid accumulation in sands above the clay aquitard beneath the newly constructed impoundment in the unlikely event of tailings fluid leaking through all three liner layers. TMW-65 is located approximately 200 feet from the proposed tailings impoundment's southwest corner. TMW-65 has been added to Figure 5-7, Proposed Monitoring Wells for the First New Tailings Impoundment and Evaporation Ponds, modified by Telesto from Shepherd Miller (1997b). Kennecott will monitor for the presence of fluid in TMW-65, and if present, will collect samples. Samples will be tested for pH, conductivity, chloride, and bromide.

Leak Detection Parameters

As required in 10 CFR 40, Appendix A, Criteria 7A, KUC proposed and the NRC accepted three indicator parameters for detection of a leak. These three indicator parameters were proposed in the Background Ground Water Quality and Detection Standards Addendum to the Revised Environmental Report (Shepherd Miller, Inc., 1996): 1) pH due to the acidity of the mill tailings, 2) conductivity, due to its proportionality to ions in the tailings fluid and as a ready contrast to low conductivity levels in the groundwater system, and 3) chloride, due to high concentrations in the mill tailings and its highly dispersive properties.

These three indicator parameters provide a marked contrast between tailings fluid and the natural groundwater system, even for groundwater at the edge of the area affected by the 1983 leak. Proposed monitoring wells have historically (30 years of data exist for these wells) exhibited low concentrations for the conductivity and chloride indicator parameters, and a relatively neutral pH. To these three parameters, Kennecott proposes that bromide sampling be added for detection of the potassium bromide tracer. Thus, progression of a significant leak from the impoundment could be quickly detected.

Battle Spring Aquifer Monitoring

Four monitoring wells are proposed as the earliest practicable indication of the unlikely event of tailings fluid leaking through all three liner layers to the Battle Spring Aquifer. The four monitoring wells meet objectives of 10 CFR 40, Appendix A, Criteria 5B(1), to "*...provide the earliest practicable warning that the impoundment is releasing hazardous constituents to the ground water*" and "*...provide prompt indication of ground-water contamination on the hydraulically downgradient edge of the disposal area.*"

Kennecott proposed, and the NRC approved, monitoring wells TMWs 31, 75, 78 and 64 as the monitoring location wells for the first new tailings impoundment, with TMW-64 being the point of compliance well. TMWs 75 and 78 would be located closest to the LDRS collection sump, which would be located in the southwest corner of the first impoundment. TMWs 31, 75 and 78 are located very close to the proposed impoundment location—each would require an upward extension of their casing because each is located within the footprint of the exterior side slopes of the impoundment. TMW-64 is located approximately 400 feet west of the southwest corner of the impoundment.

Water quality monitoring within the Battle Spring Aquifer in the vicinity of the proposed evaporation ponds was proposed by Kennecott and accepted by NRC in TMWs 3 and 50, as well as three new wells. These wells are also shown on Figure 5-7, Proposed Monitoring Wells for the First New Tailings Impoundment and Evaporation Ponds, modified by Telesto from Shepherd Miller (1997b).

All samples collected from monitoring wells will be tested for pH, conductivity, chloride, and bromide.

Upgradient and Downgradient Monitoring

The natural regional groundwater gradient below the first new tailings impoundment and evaporation pond sites is toward the southwest (Figure 2). Pumping from the Battle Spring Aquifer under the CAP results in localized water table drawdown in the vicinity of pumpback wells (Figure 2). Currently, Kennecott is pumping from TMWs 17 and 75, located north of the tailings impoundment, TMWs 7, 18, 57, 58, and 59 to the west of the impoundment, and TMWs 97 and 98 near the mill and solvent extraction buildings.

Upgradient, background groundwater monitoring for the first new tailings impoundment and evaporation ponds will occur from TMW-5, located approximately 1,200 feet east of the existing tailings impoundment (Figures 1 and 2). Construction of additional 40-acre new impoundments in this vicinity will require a new background well, to be located northeast of the future ultimate tailings storage footprint.

Proposed tailings impoundment monitoring wells TMWs 31, 64, 65, 75 and 78 (Figure 5-7) are all located either south or southwest of the first new tailings impoundment. In the unlikely event of an impoundment leak through all three liner layers, impacted groundwater would follow flow paths either in the long-term regional southwest groundwater flow direction or toward short-term localized pumping zones, also located south or southwest of the impoundment. By either flow path, each of these five wells will be located in the downgradient flow direction from the new tailings impoundment (Figure 2).

Proposed evaporation pond monitoring well TMW 3, and the three new monitoring wells will be located either south or west of the ponds. Groundwater impacted by the unlikely event of an impoundment leak through all three liner layers flowing along the regional groundwater flow path would encounter these wells (Figure 2 and modified Figure 5-7). In addition, TMW-50, north of the evaporation ponds, is proposed to be a monitoring well. This well is located between the proposed pond site and localized pumping associated with pumpback wells. In the event of an unlikely impoundment leak through all three liner layers, and if the impacted groundwater would follow a flow path toward pumping wells, TMW-50 would be downgradient of the ponds (Figure 2). Whether groundwater flow would be directed toward pumpback wells and TMW-50, or toward the southwest with the regional gradient, will depend on the magnitude of pumping.

It is intended by Kennecott to increase the volume of water removed by the pumpback system upon resumption of milling operations, using the pumpback water as process feed water to be added to the ore as it enters the semi-autogenous grinding (SAG) mill. This action will serve to increase the magnitude of the pumpback system's cone of depression and enhance the performance of the site's CAP.

SUMMARY

Groundwater monitoring is proposed as a multi-tier approach. Kennecott will inject a potassium bromide tracer solution into the tailings stream so that in the unlikely event of a leak through all three liner layers from future impoundments, the leaked fluid could be differentiated from historical excursions from the existing tailings impoundment and catchment basin into the groundwater system. Moreover, indicator parameters pH, conductivity and chloride in leaked fluids resulting from the unlikely event of an impoundment leak through all three liner layers are also likely to be differentiated from plume waters.

Kennecott will monitor water levels in the LDRS system as the first potential detection point indicating that a leak above the action leakage rate has occurred in the upper liner.

The perched zone will be monitored in TMW-65 near the southwest toe of the first new tailings impoundment for leakage that would accumulate on the clay lens located beneath this corner of the impoundment in the unlikely event of an impoundment leak through all three liner layers. The Battle Spring Aquifer in the tailings impoundment vicinity will be monitored through four wells: TMWs 31, 64, 75 and 78. The Battle Spring Aquifer in the evaporation ponds vicinity will be monitored through five wells: TMWs 3 and 50, and three newly drilled wells.

Each of the monitoring wells will be downgradient of the monitored facilities as defined by the long-term regional gradient and/or the short-term localized gradients created by operating pumping wells.

REFERENCES

Shepherd Miller, Inc. (1995). *Addendum to the Revised Environmental Report, Geologic Cross Sections and Aquifer Information.* ADAMS Accession # ML 080590245.

Shepherd Miller, Inc. (1996). *Background Ground Water Quality and Detection Standards Addendum to the Revised Environmental Report.* Fort Collins, Colorado: Shepherd Miller, Inc. January 1996.

Shepherd Miller, Inc. (1997a). *Final Design Volume IV, Existing Impoundment Reclamation Plan. Sweetwater Uranium Project.* Fort Collins, Colorado.

Shepherd Miller, Inc. (1997b). *Final Design Report, Volume VII, Operations Plan. Sweetwater Uranium Project.* Fort Collins, Colorado.: Shepherd Miller, Inc. September 1997.

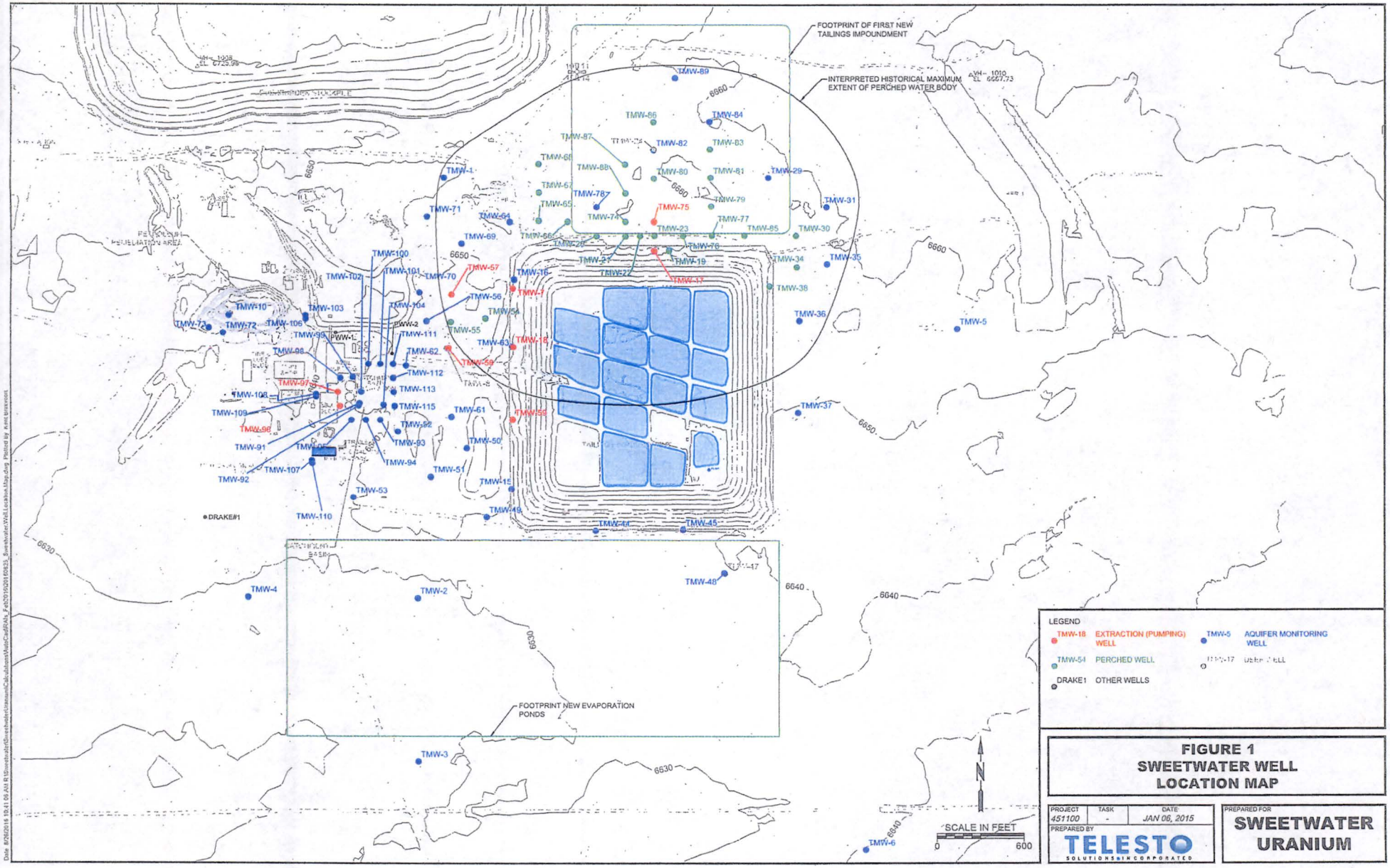


FIGURE 1
SWEETWATER WELL LOCATION MAP

PROJECT	TASK	DATE
451100	-	JAN 06, 2015

PREPARED BY TELESTO SOLUTIONS INCORPORATED

PREPARED FOR **SWEETWATER URANIUM**

Date: 8/26/2015 10:41:06 AM R:\Sweetwater\Uranium\Calculations\Mato\Cad\RAIs_Feb2015\20150825_SweetwaterWellLocation.Map.dwg Plotted by: Kent Ericsson

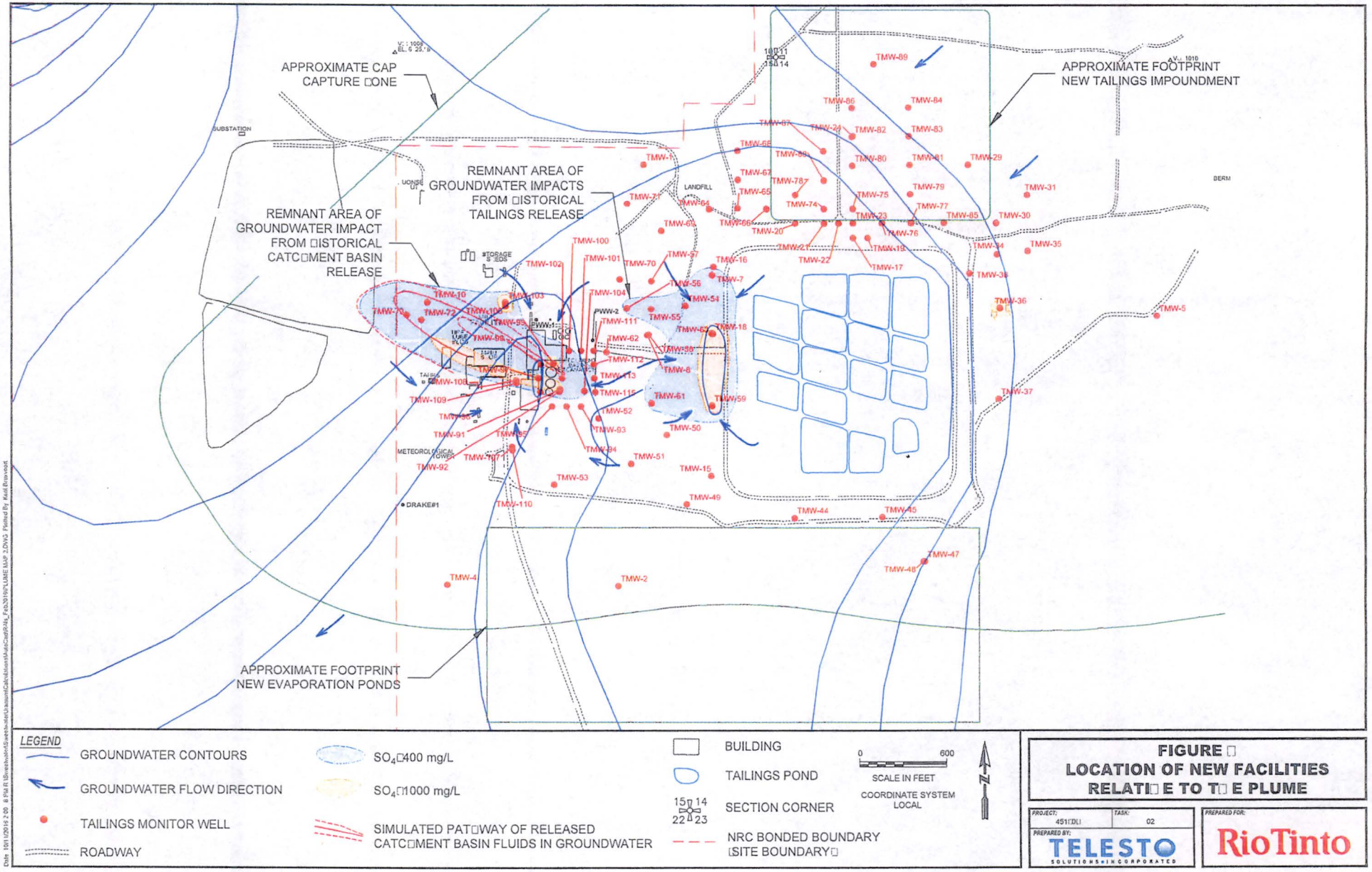


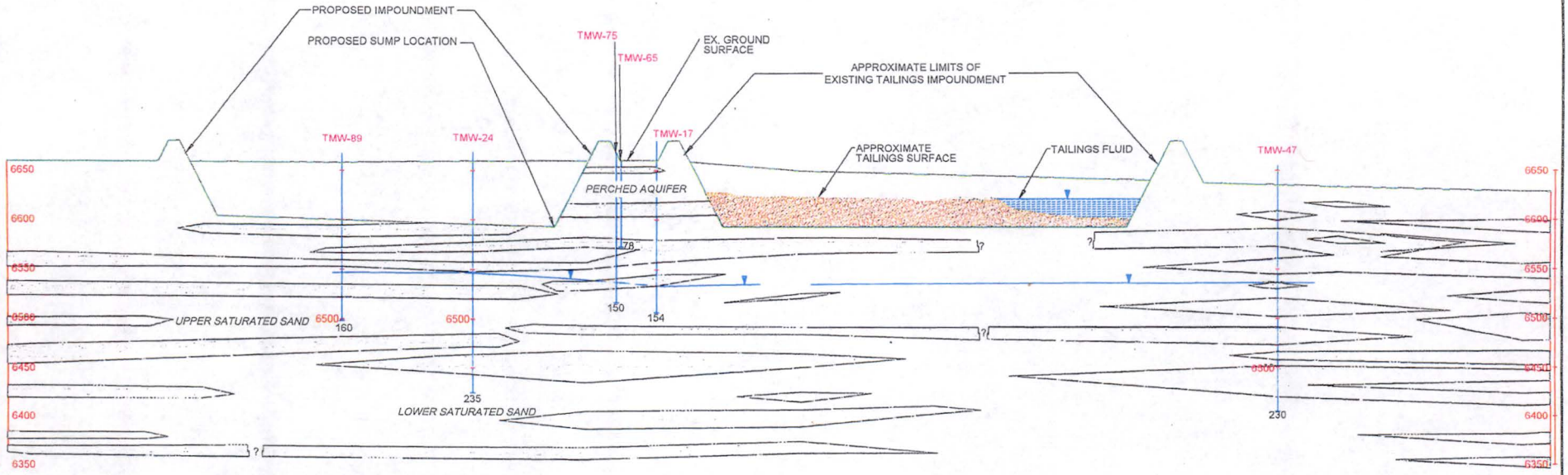
FIGURE □
LOCATION OF NEW FACILITIES RELATI□ E TO T□ E PLUME

PROJECT:	TASK:
451□DLI	02

PREPARED BY: TELESTO SOLUTIONS INCORPORATED

PREPARED FOR: Rio Tinto

Date: 10/1/2016 2:00 :8 PM R:\Envelsolon\Graphics\Uranium\Calculations\Mass\Cad\R4N_Feb2016\PLUME MAP 2.DWG Plotted By: Kurt.Bronnert



NOTE:
TMWs 89 AND 24 TO BE ABANDONED AND PLUGGED WHEN NEW IMPOUNDMENT IS CONSTRUCTED.

NOT TO SCALE

NORTH

NOTES REGARDING GROUNDWATER MONITORING:

1. FLUID LEVEL IN LEAK DETECTION AND RECOVERY SYSTEM (LDRS) TO BE MONITORED.
2. PERCHED AQUIFER NEAR SOUTHWEST CORNER OF NEW IMPOUNDMENT TO BE MONITORED (TMW-65).
3. POTASSIUM BROMIDE TRACER TO BE ADDED TO TAILINGS STREAM.
4. THREE WELLS IN BATTLE SPRING AQUIFER (TMWs 31,75 AND 78) TO BE MONITORED. TMW-64 TO BE THE POINT OF COMPLIANCE WELL.

SOURCE:

BASED ON INFORMATION PREPARED BY SHEPHERD MILLER, INC. 1995: ADDENDUM TO THE REVISED ENVIRONMENTAL REPORT, GEOLOGIC CROSS SECTIONS AND AQUIFER INFORMATION, CROSS SECTION B-B'

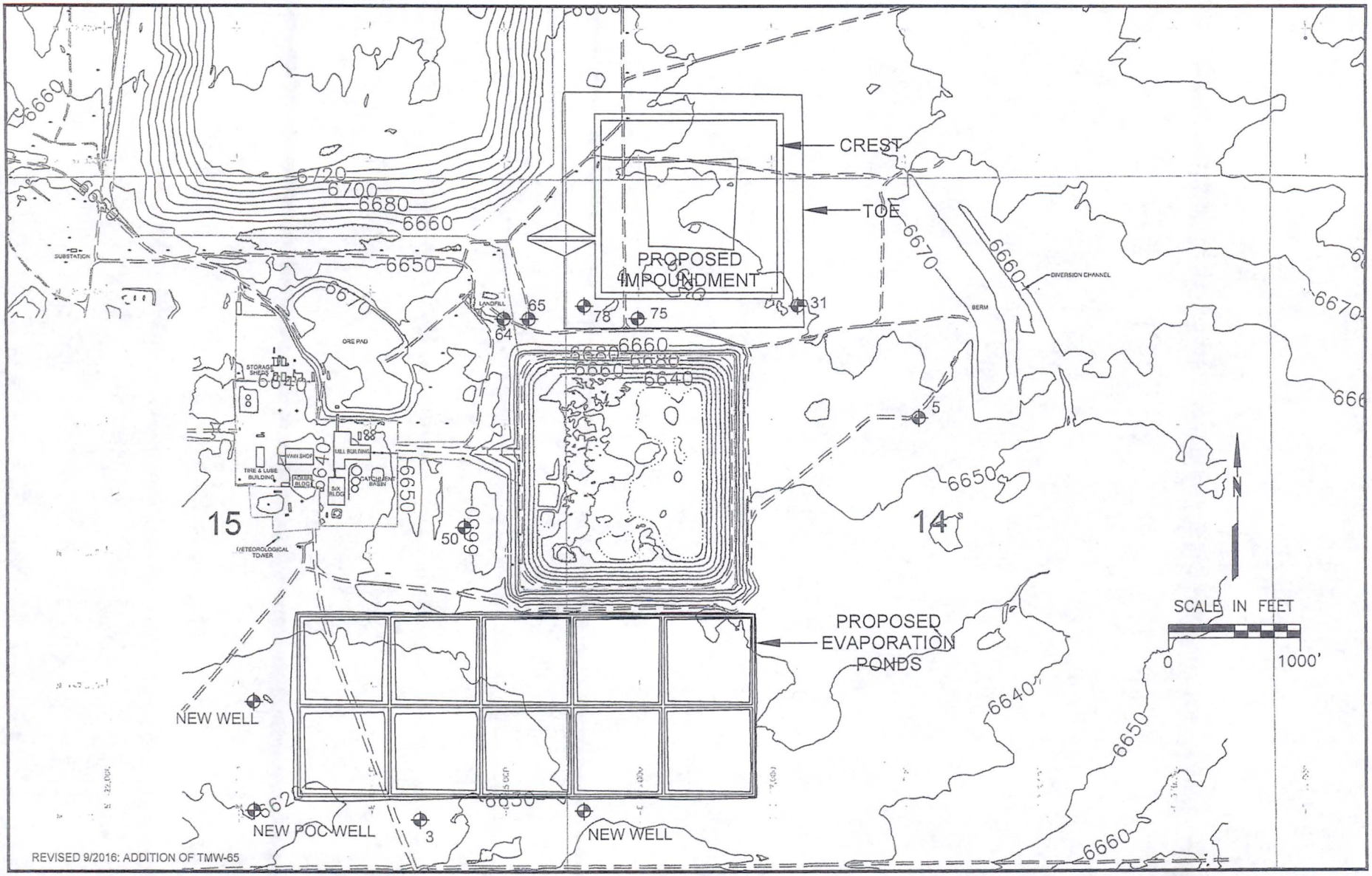
FIGURE 3
TAILINGS IMPOUNDMENT
MONITORING WELL SCHEMATIC

PROJECT:	TASK:	DATE:	DRWN BY:
451307	001	8-24-2016	ST

PREPARED BY: TELESTO

PREPARED FOR: RioTinto

Date: 10/12/2016 9:04:42 AM P:\Drawings\GIS\Swedish data\Document\Cad\Atlases\Vaste\Cad\RAIs_Feb2016\Fig_3 Geology of Battle Spring+Fenestem-20160824.dwg Plotted By: Kristi Brozzetti



PROJECT:	TASK:
415307	02

PREPARED BY: TELESTO SOLUTIONS INCORPORATED

FIGURE 5-7
PROPOSED MONITORING WELLS FOR THE FIRST NEW TAILINGS IMPOUNDMENT AND EVAPORATION PONDS

PREPARED FOR: RioTinto

ATTACHMENT 3

AIR EFFLUENT MONITORING PROGRAM

BACKGROUND

This attachment is prepared as part of Kennecott Uranium Company's (Kennecott's) license renewal application for the Sweetwater Uranium Project, License No. SUA-1350. In response to the application, the Nuclear Regulatory Commission (NRC) replied with a letter dated August 25, 2016, subject: Draft Renewal Materials License, Sweetwater Uranium Project, Sweetwater County, Wyoming. In the letter the NRC stated,

> *"Kennecott provided additional information in the Environmental Report (ER), dated June 3, 2016 discussing both the environmental monitoring program in standby and operation. According to the ER, upon resumption of operation, the environmental monitoring program will include additional environmental monitoring stations. NRC staff observed that the locations of at least one of the air sampling station(s) does not comport to Regulatory Guide 4.14. The guidance recommends that three air sampling stations be located in the three highest concentration sectors during operations. Comparing the air sampling stations (including direct radiation and soil) in Table 6.2 of the ER, to the wind rose provided in the ER (Figure 9), there is no air sampling station in the east sector during operations. This is not consistent with Regulatory Guide 4.14. An air sampling station needs to be placed in the east sector. Kennecott also indicated that air effluent monitoring will be resumed during operations. Kennecott needs to discuss in detail the air effluent monitoring program that includes both the effluent from the plant and the tailings impoundment during operation and how it will comply with 10 CFR 40.65 for quantities of radionuclides, as well as comply with 10 CFR 20.1301 and 10 CFR 20.1302. This issue will be discussed in the final SER. Therefore, License Condition 11.4 needs to address the deficiency for air sampling station in the east sector, and the air effluent monitoring upon resumption of operation."*

RESPONSE

This document provides Kennecott's response to the above comments regarding License Condition 11.4, and specifically regarding air monitoring in the east sector, and how the air effluent monitoring program will be in compliance with the above-cited regulations. Kennecott believes both responses below, and corresponding modifications to the verbiage of License Condition 11.4, will allow the license to be in compliance with Regulatory Guide 4.14 and/or 10 CFR 40.65, 10 CFR 20.1301, and 10 CFR 20.1302, as applicable.

Air Monitoring in the East Sector

The location of the air sampling stations for resumed operations was depicted in Figure 5-3: *"Nuclear Regulatory Commission Mill Area Monitoring Locations"* of *Final Design – Volume VII – Operations Plan* (Shepherd Miller, Inc., 1997. Attached please find a revised Figure 5-3 showing

the location of the air, radon, soil, vegetation and gamma monitoring station GS-3 relocated due south to a position predominately east of the yellowcake dryer stack to meet the above requirement.

A wind rose for the facility based on 2004 through 2014 data has been placed for reference on the revised Figure 5-3. The wind rose was included as Figure 9: *"Sweetwater Wind Rose, Onsite Data, 2004 through 2014"* from the *Supplement to Licensee's Environmental Report – Sweetwater Uranium Project Docket Number: 40-8584 - Source Material License: SUA-1350,* submitted to the NRC on June 3, 2016 and currently in review. The wind rose indicates a predominant wind direction at the facility toward the east and has been placed on the revised Figure 5-3 to confirm the proper placement of monitoring station GS-3 as depicted thereon. This location places the GS-3 monitoring station at the eastern edge of the Nuclear Regulatory Commission (NRC) bonded area and on the eastern edge of lands held by Kennecott Uranium Company via unpatented mill sites.

Air Effluent Monitoring Program

Stack Monitoring for Radon-222

The air effluent monitoring program for resumed operations is described in Table 5-2: *"NRC Operational Monitoring Locations and Descriptions"* in Shepherd Miller, Inc. (1997). In regards to air effluent (stack monitoring) the table provides the following:

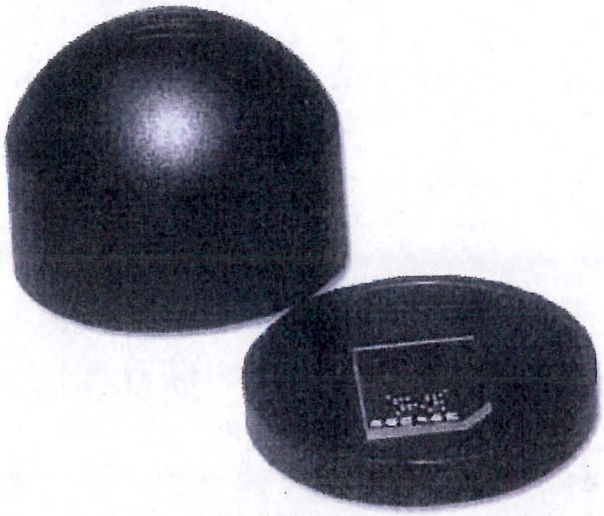
Category	Locations	Frequency	Analytical Parameters
Stack Sampling	Ore grinding, leach, and yellowcake dryer stacks	Semiannually (ore and leach), Quarterly (yellowcake)	Natural uranium, Ra-226, Th-230, Pb-210 (also stack flow rate when sampled)

This sampling protocol addresses natural uranium, radium-226, thorium-230 and lead-210 as well as flow rates (semiannually for ore grinding and leach) and quarterly for the yellowcake dryer stack. Sampling will be performed in accordance with *"Environmental Procedure EP-15 – Stack Sampling"* and *"EPA Method 5 – Determination of Particulate Emissions from Stationary Sources,"* the latter of which is attached in Appendix 1.

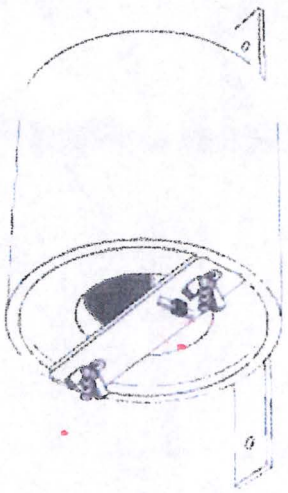
Monitoring for radon is not included in the above table. The section on stack sampling in Table 5-2: *"NRC Operational Monitoring Locations and Descriptions"* in Shepherd Miller, Inc. (1997) shall be modified to add radon-222 to the list of analytical parameters to read as follows:

Category	Locations	Frequency	Analytical Parameters
Stack Sampling	Ore grinding, leach, and yellowcake dryer stacks	Semiannually (ore and leach), Quarterly (yellowcake)	Natural uranium, Ra-226, Th-230, Pb-210 and Rn-222 (also stack flow rate when sampled)

Radon concentration in air shall be determined using Landauer, Inc.'s Rapidos HS detectors mounted in the stack in a specially designed protective canister that is available for outdoor applications and supplied by Landauer, Inc. These detectors are described in Appendix 2, which contains a presentation entitled "*High-Sensitivity Radon Measurements With Passive Alpha-Track Detectors,*" dated June 6, 2016 by Tryggve Rönnqvist, PhD Technical Manager Landauer Nordic AB. A Landauer Rapidos HS unit is shown below:



The grinding, leaching and/or yellowcake dryer stacks may have to be modified, including by widening, to accommodate the outdoor holder for the Rapidos HS units. The yellowcake stack may be modified (lengthened and/or widened) to promote cooling of the exhaust to ensure that the exhaust does not cause thermal damage to the detector. The protective canister is shown below:



Instructions for the Rapidos HS units are included in Appendix 3.

The use of Landauer, Inc.'s Rapidos HS detectors was discussed via e-mail with Bill Rounds of Landauer, Inc. He in turn conferred with Tryggve Ronnqvist of Landauer Nordic. In an e-mail to Oscar A. Paulson, Kennecott, dated Wednesday, August 24, 2016, Bill Rounds stated:

> *"The HS-Rapidos service is recommended for any outdoor or industrial applications. Not only is the LDL lower, background lower, and uncertainty lower, it is a more precise and more reliable measurement. The measure area is 60% larger, sensitivity of 4.6 vs 2.3 tracks/cm2 per pCi-d/l, there are tighter quality requirements on CR-39 material used in production, and the service incorporates transit controls to all but eliminate non-measure point exposure from handling, transport, etc. Acceptability for margin of error is fairly large for indoor measurements. While we are well within the range and arguably perform the best of all mass produced ATD devices, there is no debate the HS-Rapidos service is superior in many regards. In the residential l/t test market there are competing devices that do not perform nearly as well as either of our devices, yet we have to compete with them on price due to the existence of only one recognized performance standard in most tenders – that the device meets the NRPP performance criteria, which quite candidly, is broad. Rapidos is the better device and service for your application, and would be our recommendation. The measure period length would depend on the levels – higher the level shorter the period would need to be to avoid saturation / MDL. Rapidos range is 1-2800 pCi/l at 10 days, or 28,000 pCi-d/l."*

It is initially intended to exchange the Rapidos HS detectors in the stacks quarterly at the same time and frequency as the detectors are exchanged at the air monitoring stations. However, if levels of radon in the stacks are high, the exchange interval would be shortened to avoid saturation of the detector. Upon resumption of operations, more than one detector would be initially installed in the stack with one exchanged at a shorter interval (one (1) month) to ensure that radon levels will not saturate a detector over three (3) months.

The detector manufacturer recommends use of the Rapidos HS detectors for the application in question (stack monitoring). While some concerns have been raised regarding the use of these devices in stack monitoring, data has been gathered by Energy Fuels Resources (USA) Inc. and presented on June 18, 2014 in a presentation given at the annual National Mining Association (NMA) Uranium Recovery Workshop entitled *"Radon Emissions Monitoring at Uranium Mines: Comparison of Alpha Track Detectors and Scintillation Cell Monitors,"* which concluded:

- *ATDs (alpha track detectors) produce comparable, consistent, continuous, and reliable data.*
- *Scintillation cell monitors provide accurate and representative data, however, the devices proved to be unreliable and labor intensive in outdoor environments.*
- *ATDs produce data comparable to scintillation cell monitors at lower radon concentrations. (<200 pCi/L)*
- *ATDs overestimate radon concentrations in high velocity environments which result in higher radon concentrations (>200 pCi/L)*
- *Overall results were suitable for developing a calibration factor to account for overestimation when determining annual NESHAPs compliance.*

Based on the conclusions above, the alpha track detectors would err (if they did) toward being conservative since they overestimate radon concentrations in high velocity environments. This presentation is included in Appendix 4.

The Environmental Protection Agency (EPA) document *"Method 114 - Test Methods For Measuring Radionuclide Emission From Stationary Sources"* states:

> *"3.1.7 Method A-7, Radon-222-Alpha Track Detectors*
> *Principle: Radon-222 is measured directly in the effluent stream using alpha track detectors (ATD). The alpha particles emitted by radon-222 and its decay products strike a small plastic strip and produce submicron damage tracks. The plastic strip is placed in a caustic solution that accentuates the damage tracks which are counted using a microscope or automatic counting system. The number of tracks per unit area is correlated to the radon concentration in air using a conversion factor derived from data generated in a radon calibration facility.*
> *Applicability: Prior approval from EPA is required for use of this method. This method is only applicable to effluent streams which do not contain significant quantities of radon-220, unless special detectors are used to discriminate against radon-220. This method may be used only when ATDs have been demonstrated to produce data comparable to data obtained with Method A-6. Such data should be submitted to EPA when requesting approval for the use of this method. EPA 520/1-89-009(24)."*

Please note that Method A-6 is a Radon-222-Continuous Gas Monitor specifically a scintillation (Lucas) cell monitor.

Kennecott is attaching the presentation entitled *"Radon Emissions Monitoring at Uranium Mines: Comparison of Alpha Track Detectors and Scintillation Cell Monitors* (Appendix 4) to show that *"... ATDs have been demonstrated to produce data comparable to data obtained with Method A-*

6" and thus should be allowed for use in stack monitoring for radon at the Sweetwater Uranium Project especially in light of the fact that they err toward being conservative at high stack flow velocities.

In addition, use of alpha track detectors has been permitted by the EPA to monitor radon in the mine ventilation exhaust drift at the Jackpot Mine in Fremont County, Wyoming. Such permission was granted by the agency on September 17, 1997. Use of these detectors continued at the mine until the mine openings were closed by August 16, 2001.

Should the alpha track detectors prove unsatisfactory upon use, Kennecott would employ scintillation cell monitors (Lucas Cells).

Tailings Impoundment Monitoring

The newly constructed tailings impoundments, while actively receiving tailings, will not require discrete monitoring for the following reasons:

- The new impoundments are designed as forty (40) acre impoundments in compliance with the current version of 40 CFR part 61 Subpart W which states:
  - ***§ 61.252 Standard.***

    (a) Radon-222 emissions to the ambient air from an existing uranium mill tailings pile shall not exceed 20 pCi/(m 2-sec) (1.9 pCi/(ft 2-sec)) of radon-222.

    (b) After December 15, 1989, no new tailings impoundment can be built unless it is designed, constructed and operated to meet one of the two following work practices:

    (1) Phased disposal in lined tailings impoundments that are no more than 40 acres in area and meet the requirements of 40 CFR 192.32(a) as determined by the Nuclear Regulatory Commission. The owner or operator shall have no more than two impoundments, including existing impoundments, in operation at any one time.

    (2) Continuous disposal of tailings such that tailings are dewatered and immediately disposed with no more than 10 acres uncovered at any time and operated in accordance with § 192.32(a) as determined by the Nuclear Regulatory Commission.

    (c) All mill owners or operators shall comply with the provisions of 40 CFR 192.32(a) in the operation of tailings piles, the exemption for existing piles in 40 CFR 192.32(a) notwithstanding.
- Since these impoundments were designed and will be constructed after December 15, 1989, they will meet the work practice requirement of being no more that forty (40) acres in area hence annual flux testing as per Method 115 is not required.
- The impoundments are designed to be operated as per Shepherd Miller, Inc. (1997) to:
  - Maintain a moist tailings surface and;

- Control the location and extent of the free water pool.

- Since the tailings will be partially covered by a free pool and kept wet in other areas emissions will be minimized. The "*Final Design – Volume VII – Operations Plan*" (Shepherd Miller, Inc., 1997) states:

  > *"Tailings disposal will occur by discharging tailings from multiple spigots along one cell wall. The spigots will connect to HDPE tailings lines. Holes will be drilled near the outlets of the tailings lines to allow a controlled energy discharge. As the tailings elevation increases, additional holes will be drilled ahead of the advancing tailings edge. Discharge spigots will be alternated periodically to optimize beach development and to wet the tailings surface to minimize windblown dust potential."*

- Continuous discharge of tailings slurry into the impoundment and down the beach slope toward the free pool would prevent any radon flux testing using Large Area Activated Charcoal Canisters (LAACCs) on the tailings surface as per Method 115 and more specifically described in "*Radon Flux Measurements on Gardinier and Royster Phosphogypsum Piles near Tampa and Mulberry, Florida*" (Hartley, J.N., and Freeman, H.D., January 1986). Annual Method 115 testing of newly constructed tailings impoundment surfaces was discussed with NRC staff as a means of determining the total activity of radon-222 released as an effluent from the impoundment annually. Such testing is not practical since the LAACC units would be caught in the flow of tailings slurry on the surface of the tailings beach on which measurements were being attempted. Moreover, personnel safety and exposure would be compromised, against the ALARA principle, in placing and recovering LAACCs during the process of active tailings deposition.
- Since direct measurement of radon emissions from the new impoundment cannot be done due to the ongoing continuous deposition of tailings slurry, the calculated radon emission rates for the tailings impoundment listed in Table 5.2-1 of the facility's Revised Environmental Report (Shepherd Miller, Inc., 1994) will be used as estimates of the activity of radon released to the environment, or they will be based upon calculations from Regulatory Guide 3.59 *(Task WM 407-4): "Methods for Estimating Radioactive and Toxic Airborne Source Terms for Uranium Milling Operations*." If values from Table 5.2-1 of the Revised Environmental Report (Shepherd Miller, Inc., 1994) are used, and should the grades of material processed in the mill differ from the 0.2 per cent U_3O_8 used to estimate the emission rate, then the emission rate will be adjusted linearly based upon the different feed grade. This linear adjustment was discussed in Section 5.2.3 of the Revised Environmental Report (Shepherd Miller, Inc., 1994), in a sub-section entitled "*Dose Variations with Ore Grade*."
- The wet tailings surface and partial free pool would minimize dusting.
- Air monitoring station GS-3 would lie east of the new impoundment providing an effective means of verifying that the operation of the impoundment is not resulting in dusting or excessive radon releases since monitoring for airborne particulates and radon would be performed at that location.

- The 40.65 Report, discussed below, for the second half of each year will include the results of a MILDOS model using the calculated activities of the radionuclides released to the air for the calendar year and run to calculate a dose to individual members of the public from the licensed operation. The MILDOS model, which will include radon emanation from the tailings as one of the source terms, will document the level of dose expected to occur, and expected to be minimized as a result of tailings management methods employed by the licensee. The model results will also be an operational confirmation of pre-operational modeling prepared for the facility's Revised Environmental Report (Shepherd Miller, Inc., 1994).

Compliance with 10 CFR 40.65

Kennecott's proposed air monitoring program will comply with 10 CFR 40.65, which states:

> ***§ 40.65 Effluent monitoring reporting requirements.***
>
> *"(a) Each licensee authorized to possess and use source material in uranium milling, in production of uranium hexafluoride, or in a uranium enrichment facility shall:*
>
> *(1) Within 60 days after January 1, 1976 and July 1, 1976, and within 60 days after January 1 and July 1 of each year thereafter, submit a report to the Director, Office of Nuclear Material Safety and Safeguards, using an appropriate method listed in § 40.5, with a copy to the appropriate NRC Regional Office shown in appendix D to part 20 of this chapter; the report must specify the quantity of each of the principal radionuclides released to unrestricted areas in liquid and in gaseous effluents during the previous six months of operation, and such other information as the Commission may require to estimate maximum potential annual radiation doses to the public resulting from effluent releases. If quantities of radioactive materials released during the reporting period are significantly above the licensee's design objectives previously reviewed as part of the licensing action, the report shall cover this specifically. On the basis of such reports and any additional information the Commission may obtain from the licensee or others, the Commission may from time to time require the licensee to take such action as the Commission deems appropriate."*

Regulation 10 CFR 40.65 requires semiannual reporting. The air effluent monitoring protocols discussed above provide for semiannual measurement of natural uranium, radium-226, thorium-230, lead-210 and radon-222 as well as exhaust flow rate from the grinding and leach area stacks; and quarterly measurement of natural uranium, radium-226, thorium-230, lead-210 and radon-222 as well as exhaust flow rate from the yellowcake dryer stack. The use of the stack flow rates and the activities of the natural uranium, radium-226, thorium-230, lead-210 and radon-222 in the exhaust flow will allow for a semiannual calculation of "*...the quantity of each of the principal radionuclides released to unrestricted areas in liquid and in gaseous effluents during the previous six months of operation,...*" as required by 10 CFR 40.65.

Compliance with 10 CFR 20.1301 and 10 CFR 20.1302

Kennecott's proposed air monitoring program will comply with 10 CFR 20.1301, which states in part:

> ***§ 20.1301 Dose limits for individual members of the public.***
>
> > *"(a) Each licensee shall conduct operations so that -*
> >
> > *(1) The total effective dose equivalent to individual members of the public from the licensed operation does not exceed 0.1 rem (1 mSv) in a year, exclusive of the dose contributions from background radiation, from any administration the individual has received, from exposure to individuals administered radioactive material and released under § 35.75, from voluntary participation in medical research programs, and from the licensee's disposal of radioactive material into sanitary sewerage in accordance with § 20.2003, and*
> >
> > *(2) The dose in any unrestricted area from external sources, exclusive of the dose contributions from patients administered radioactive material and released in accordance with § 35.75, does not exceed 0.002 rem (0.02 millisievert) in any one hour.*
> >
> > *(b) If the licensee permits members of the public to have access to controlled areas, the limits for members of the public continue to apply to those individuals."*

Kennecott's proposed air monitoring program will comply with 10 CFR 20.1302, which states in part:

> ***§ 20.1302 Compliance with dose limits for individual members of the public.***
>
> > *(a) The licensee shall make or cause to be made, as appropriate, surveys of radiation levels in unrestricted and controlled areas and radioactive materials in effluents released to unrestricted and controlled areas to demonstrate compliance with the dose limits for individual members of the public in § 20.1301.*
> >
> > *(b) A licensee shall show compliance with the annual dose limit in § 20.1301 by--*
> >
> > *(1) Demonstrating by measurement or calculation that the total effective dose equivalent to the individual likely to receive the highest dose from the licensed operation does not exceed the annual dose limit; or*
> >
> > *(2) Demonstrating that--*
> >
> > > *(i) The annual average concentrations of radioactive material released in gaseous and liquid effluents at the boundary of the unrestricted area do not exceed the values specified in table 2 of appendix B to part 20; and*

(ii) If an individual were continuously present in an unrestricted area, the dose from external sources would not exceed 0.002 rem (0.02 mSv) in an hour and 0.05 rem (0.5 mSv) in a year.

(c) Upon approval from the Commission, the licensee may adjust the effluent concentration values in appendix B to part 20, table 2, for members of the public, to take into account the actual physical and chemical characteristics of the effluents (e.g., aerosol size distribution, solubility, density, radioactive decay equilibrium, chemical form).

Verification of compliance with the 10 CFR 20.1301 0.1 rem (100 millirem) dose limit and the 10 CFR 20.1302 requirements for compliance demonstration for individual members of the public has been discussed on multiple occasions with James Webb of the Division of Decommissioning, Uranium Recovery, & Waste Programs. Based on these conversations and Kennecott experience, Kennecott will achieve compliance verification following renewal of the source material license via the following process:

- Stack sampling data for natural uranium, radium-226, thorium-230, and lead-210 will be acquired semiannually for the grinding and leach area stacks and quarterly for the yellowcake dryer stack using *EPA Method 5 – Determination of Particulate Emissions from Stationary Sources*.
- Flow rates for the stacks will be measured semiannually for the grinding and leach area stacks and quarterly for the yellowcake dryer stack.
- Radon-222 concentrations in exhausts from the grinding and leach area stacks and the yellowcake dryer stack will be measured continuously using alpha track detectors, exchanged at least quarterly, and more frequently if there is a danger of saturation of the detector.
- Radon emissions from non-operating tailings impoundment(s) (impoundments not accepting tailings) will be determined based upon an annual Method 115 Test of the non-operating impoundment(s). Radon emissions from operating tailings impoundment(s) (impoundments accepting tailings) will be either be based upon the calculated radon emission rates for the tailings impoundment listed in Table 5.2-1 of the Revised Environmental Report (Shepherd Miller, Inc., 1994) adjusted linearly for differences in uranium grade from the assumed grade used in the preparation of the table or based upon calculations from Regulatory Guide 3.59 *(Task WM 407-4): "Methods for Estimating Radioactive and Toxic Airborne Source Terms for Uranium Milling Operations."*
- This information (activities in air and air flow rates) will be used to calculate the total activities of natural uranium, radium-226, thorium-230, lead-210 and radon-222 released to the air to meet the requirements of 10 CFR Part 40.65 when it requires, "*...the quantity of each of the principal radionuclides released to unrestricted areas in liquid and in gaseous effluents during the previous six months of operation...*".
- This information will be presented annually in both the first and second half 40.65 Reports.
- The 40.65 Report for the second half of each year will include the results of a MILDOS model using the calculated activities of the radionuclides released to the air for the calendar year and run to calculate a dose to the individual members of the public from the licensed operation.

REFERENCES

Energy Fuels Resources (USA), Inc. (2014). *Radon Emissions Monitoring at Uranium Mines: Comparison of Alpha Track Detectors and Scintillation Cell Monitors,"* presentation given at the annual National Mining Association (NMA) Uranium Recovery Workshop.

Hartley, J.N., and Freeman, H.D. (1986). *"Radon Flux Measurements on Gardinier and Royster Phosphogypsum Piles near Tampa and Mulberry, Florida".* Prepared for the U.S. Environmental Protection Agency. EPA 520/5-85-029. January 1986.

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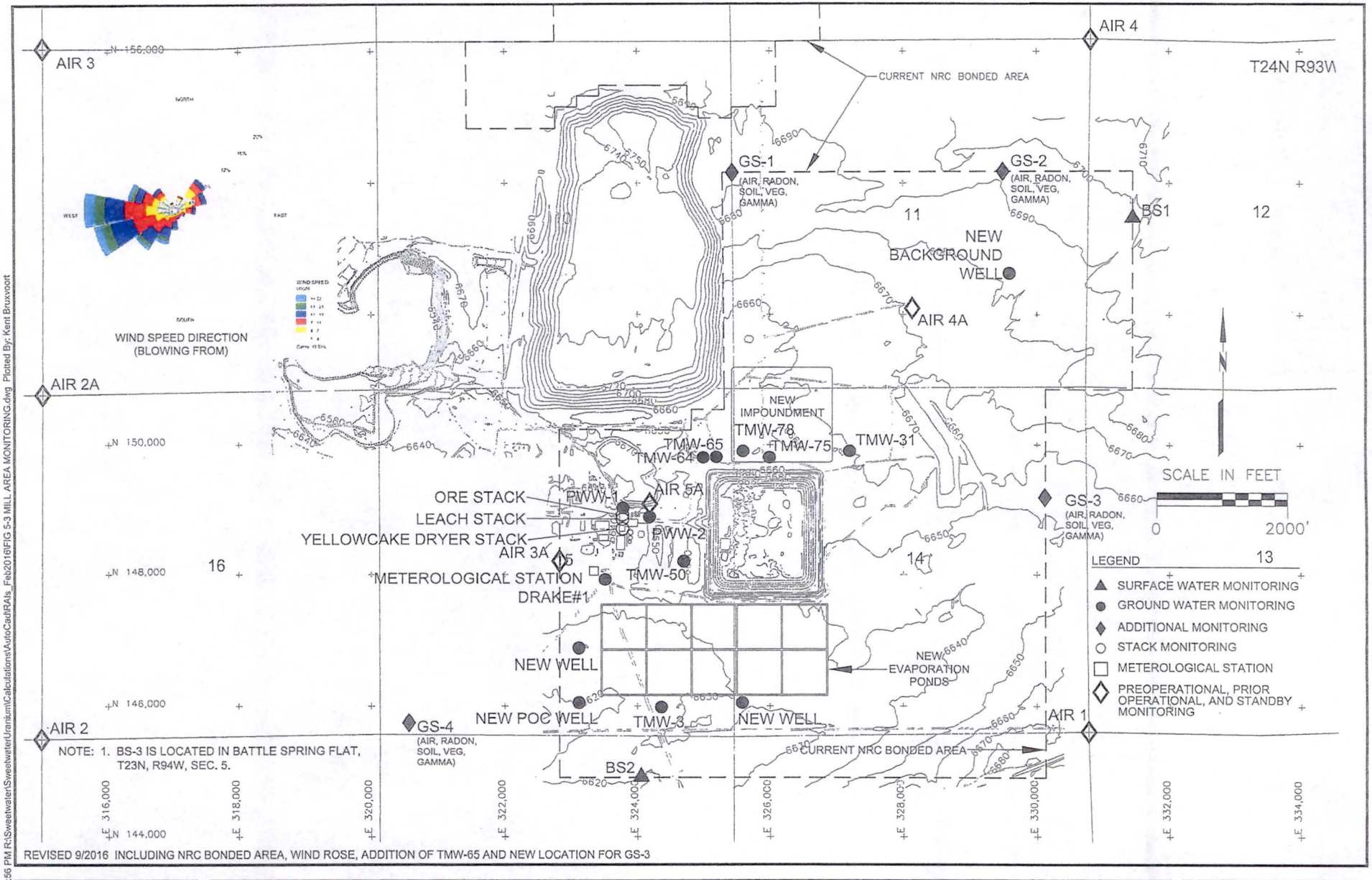
U.S. Environmental Protection Agency. *"Method 5—Determination of Particulate Matter Emissions from Stationary Sources.*

U.S. Environmental Protection Agency. *"Method 114—Test Methods for Measuring Radionuclide Emission from Stationary Sources."*

U.S. Nuclear Regulatory Commission. (1987). *Regulatory Guide 3.59 (Task WM 407-4): "Methods for Estimating Radioactive and Toxic Airborne Source Terms for Uranium Milling Operations."* ADAMS Accession # ML 003739503. March 1987.



Date: 10/11/2016 1:30:56 PM R:\Sweetwater\SweetwaterUranium\Calculations\AutoCad\RAIs_Feb2016\FIG 5-3 MILL AREA MONITORING.dwg Plotted By: Kent Bruxvoort

PROJECT:	TASK:
415307	02

TELESTO SOLUTIONS INCORPORATED

FIGURE 5-3
NRC MILL AREA MONITORING LOCATIONS, RESUMED OPERATIONS, FIRST NEW TAILINGS IMPOUNDMENT AND EVAPORATION PONDS

PREPARED FOR: Rio Tinto

APPENDIX 1

While we have taken steps to ensure the accuracy of this Internet version of the document, it is not the official version. Please refer to the official version in the FR publication, which appears on the Government Printing Office's eCFR website:
HTTP://WWW.ECFR.GOV/CGI-BIN/TEXT-IDX?SID=C7836E6FF67E5AD001BCB19CCFD99C1A&NODE=40:8.0.1.1.1&RGN=DIV5#40:8.0.1.1.1.0.1.1.3

METHOD 5—DETERMINATION OF PARTICULATE MATTER EMISSIONS FROM STATIONARY SOURCES

NOTE: This method does not include all of the specifications (*e.g.,* equipment and supplies) and procedures (*e.g.,* sampling and analytical) essential to its performance. Some material is incorporated by reference from other methods in this part. Therefore, to obtain reliable results, persons using this method should have a thorough knowledge of at least the following additional test methods: Method 1, Method 2, Method 3.

1.0 Scope and Application

1.1 Analyte. Particulate matter (PM). No CAS number assigned.

1.2 Applicability. This method is applicable for the determination of PM emissions from stationary sources.

1.3 Data Quality Objectives. Adherence to the requirements of this method will enhance the quality of the data obtained from air pollutant sampling methods.

2.0 Summary of Method

Particulate matter is withdrawn isokinetically from the source and collected on a glass fiber filter maintained at a temperature of 120 ±14 °C (248 ±25 °F) or such other temperature as specified by an applicable subpart of the standards or approved by the Administrator for a particular application. The PM mass, which includes any material that condenses at or above the filtration temperature, is determined gravimetrically after the removal of uncombined water.

3.0 Definitions [Reserved]

4.0 Interferences [Reserved]

5.0 Safety

5.1 Disclaimer. This method may involve hazardous materials, operations, and equipment. This test method may not address all of the safety problems associated with its use. It is the responsibility of the user of this test method to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to performing this test method.

6.0 Equipment and Supplies

6.1 Sample Collection. The following items are required for sample collection:

6.1.1 Sampling Train. A schematic of the sampling train used in this method is shown in Figure 5-1 in section 18.0. Complete construction details are given in APTD-0581 (Reference 2 in section 17.0); commercial models of this train are also available. For changes from APTD-0581 and for allowable modifications of the train shown in Figure 5-1, see the following subsections.

NOTE: The operating and maintenance procedures for the sampling train are described in APTD-0576 (Reference 3 in section 17.0). Since correct usage is important in obtaining valid results, all users should read APTD-0576 and adopt the operating and maintenance procedures outlined in it, unless otherwise specified herein.

6.1.1.1 Probe Nozzle. Stainless steel (316) or glass with a sharp, tapered leading edge. The angle of taper shall be $\leq 30°$, and the taper shall be on the outside to preserve a constant internal diameter. The probe nozzle shall be of the button-hook or elbow design, unless otherwise specified by the Administrator. If made of stainless steel, the nozzle shall be constructed from seamless tubing. Other materials of construction may be used, subject to the approval of the Administrator. A range of nozzle sizes suitable for isokinetic sampling should be available. Typical nozzle sizes range from 0.32 to 1.27 cm ($\frac{1}{8}$ to $\frac{1}{2}$in) inside diameter (ID) in increments of 0.16 cm ($\frac{1}{16}$ in). Larger nozzles sizes are also available if higher volume sampling trains are used. Each nozzle shall be calibrated, according to the procedures outlined in section 10.1.

6.1.1.2 Probe Liner. Borosilicate or quartz glass tubing with a heating system capable of maintaining a probe gas temperature during sampling of 120 ±14 °C (248 ±25 °F), or such other temperature as specified by an applicable subpart of the standards or as approved by the Administrator for a particular application. Since the actual temperature at the outlet of the probe is not usually monitored during sampling, probes constructed according to APTD-0581 and utilizing the calibration curves of APTD-0576 (or calibrated according to the procedure outlined in APTD-0576) will be considered acceptable. Either borosilicate or quartz glass probe liners may be used for stack temperatures up to about 480 °C (900 °F); quartz glass liners shall be used for temperatures between 480 and 900 °C (900 and 1,650 °F). Both types of liners may be used at higher temperatures than specified for short periods of time, subject to the approval of the Administrator. The softening temperature for borosilicate glass is 820 °C (1500 °F), and for quartz glass it is 1500 °C (2700 °F). Whenever practical, every effort should be made to use borosilicate or quartz glass probe liners. Alternatively, metal liners (e.g., 316 stainless steel, Incoloy 825 or other corrosion resistant metals) made of seamless tubing may be used, subject to the approval of the Administrator.

6.1.1.3 Pitot Tube. Type S, as described in section 6.1 of Method 2, or other device approved by the Administrator. The pitot tube shall be attached to the probe (as shown in Figure 5-1) to allow constant monitoring of the stack gas velocity. The impact (high pressure) opening plane of the pitot tube shall be even with or above the nozzle entry plane (see Method 2, Figure 2-7) during sampling. The Type S pitot tube assembly shall have a known coefficient, determined as outlined in section 10.0 of Method 2.

6.1.1.4 Differential Pressure Gauge. Inclined manometer or equivalent device (two), as described in section 6.2 of Method 2. One manometer shall be used for velocity head (Δp) readings, and the other, for orifice differential pressure readings.

6.1.1.5 Filter Holder. Borosilicate glass, with a glass or Teflon frit filter support and a silicone rubber gasket. Other materials of construction (e.g., stainless steel or Viton) may be used, subject to the approval of the Administrator. The holder design shall provide a positive seal against leakage from the outside or around the filter. The holder shall be attached immediately at the outlet of the probe (or cyclone, if used).

6.1.1.6 Filter Heating System. Any heating system capable of monitoring and maintaining temperature around the filter shall be used to ensure the sample gas temperature exiting the filter of 120 ± 14 °C (248 ± 25 °F) during sampling or such other temperature as specified by an applicable subpart of the standards or approved by the Administrator for a particular application. The monitoring and regulation of the temperature around the filter may be done with the filter temperature sensor or another temperature sensor.

6.1.1.7 Filter Temperature Sensor. A temperature sensor capable of measuring temperature to within ±3 °C (5.4 °F) shall be installed so that the sensing tip of the temperature sensor is in direct contact with the sample gas exiting the filter. The sensing tip of the sensor may be encased in glass, Teflon, or metal and must protrude at least ½ in. into the sample gas exiting the filter. The filter temperature sensor must be monitored and recorded during sampling to ensure a sample gas temperature exiting the filter of 120 ± 14 °C (248 ± 25 °F), or such other temperature as specified by an applicable subpart of the standards or approved by the Administrator for a particular application.

6.1.1.8 Condenser. The following system shall be used to determine the stack gas moisture content: Four impingers connected in series with leak-free ground glass fittings or any similar leak-free noncontaminating fittings. The first, third, and fourth impingers shall be of the Greenburg-Smith design, modified by replacing the tip with a 1.3 cm (½ in.) ID glass tube extending to about 1.3 cm (½ in.) from the bottom of the flask. The second impinger shall be of the Greenburg-Smith design with the standard tip. Modifications (e.g., using flexible connections between the impingers, using materials other than glass, or using flexible vacuum lines to connect the filter holder to the condenser) may be used, subject to the approval of the Administrator. The first and second impingers shall contain known quantities of water (Section 8.3.1), the third shall be empty, and the fourth shall contain a known weight of silica gel, or equivalent desiccant. A temperature sensor, capable of measuring temperature to within 1 °C (2 °F) shall be placed at the outlet of the fourth impinger for monitoring purposes. Alternatively, any system that cools the sample gas stream and allows measurement of the water condensed and moisture leaving the condenser, each to within 1 ml or 1 g may be used, subject to the approval of the Administrator. An acceptable technique involves the measurement of condensed water either gravimetrically or volumetrically and the determination of the moisture leaving the condenser by: (1) monitoring the temperature and pressure at the exit of the condenser and using Dalton's law of partial pressures; or (2) passing the sample gas stream through a tared silica gel (or equivalent desiccant) trap with exit gases kept below 20 °C (68 °F) and determining the weight gain. If means other than silica gel are used to determine the amount of moisture leaving the condenser, it is recommended that silica gel (or equivalent) still be used between the condenser system and pump to prevent moisture condensation in the pump and metering devices and to avoid the need to make corrections for moisture in the metered volume.

NOTE: If a determination of the PM collected in the impingers is desired in addition to moisture content, the impinger system described above shall be used, without modification. Individual States or control agencies requiring this information shall be contacted as to the sample recovery and analysis of the impinger contents.

6.1.1.9 Metering System. Vacuum gauge, leak-free pump, calibrated temperature sensors (rechecked at at least one point after each test), dry gas meter (DGM) capable of measuring volume to within 2 percent, and related equipment, as shown in Figure 5-1. Alternatively, an Isostack metering system may be used if all Method 5 calibrations are performed, with the exception of those related to ΔH@ in Section 9.2.1, wherein the sample flow rate system shall be calibrated in lieu of ΔH@ and shall not deviate by more than 5 percent. Other metering systems capable of maintaining sampling rates within 10 percent of isokinetic and of determining sample volumes to within 2 percent may be used, subject to the approval of the Administrator. When the metering system is used in conjunction with a pitot tube, the system shall allow periodic checks of isokinetic rates.

6.1.1.10 Sampling trains utilizing metering systems designed for higher flow rates than that described in APTD-0581 or APTD-0576 may be used provided that the specifications of this method are met.

6.1.2 Barometer. Mercury, aneroid, or other barometer capable of measuring atmospheric pressure to within 2.5 mm Hg (0.1 in.).

NOTE: The barometric pressure reading may be obtained from a nearby National Weather Service station. In this case, the station value (which is the absolute barometric pressure) shall be requested and an adjustment for elevation differences between the weather station and sampling point shall be made at a rate of minus 2.5 mm Hg (0.1 in.) per 30 m (100 ft) elevation increase or plus 2.5 mm Hg (0.1 in) per 30 m (100 ft) elevation decrease.

6.1.3 Gas Density Determination Equipment. Temperature sensor and pressure gauge, as described in sections 6.3 and 6.4 of Method 2, and gas analyzer, if necessary, as described in Method 3. The temperature sensor shall, preferably, be permanently attached to the pitot tube or sampling probe in a fixed configuration, such that the tip of the sensor extends beyond the leading edge of the probe sheath and does not touch any metal. Alternatively, the sensor may be attached just prior to use in the field. Note, however, that if the temperature sensor is attached in the field, the sensor must be placed in an interference-free arrangement with respect to the Type S pitot tube openings (see Method 2, Figure 2-4). As a second alternative, if a difference of not more than 1 percent in the average velocity measurement is to be introduced, the temperature sensor need not be attached to the probe or pitot tube. (This alternative is subject to the approval of the Administrator.)

6.2 Sample Recovery. The following items are required for sample recovery:

6.2.1 Probe-Liner and Probe-Nozzle Brushes. Nylon bristle brushes with stainless steel wire handles. The probe brush shall have extensions (at least as long as the probe) constructed of

stainless steel, Nylon, Teflon, or similarly inert material. The brushes shall be properly sized and shaped to brush out the probe liner and nozzle.

6.2.2 Wash Bottles. Two Glass wash bottles are recommended. Alternatively, polyethylene wash bottles may be used. It is recommended that acetone not be stored in polyethylene bottles for longer than a month.

6.2.3 Glass Sample Storage Containers. Chemically resistant, borosilicate glass bottles, for acetone washes, 500 ml or 1000 ml. Screw cap liners shall either be rubber-backed Teflon or shall be constructed so as to be leak-free and resistant to chemical attack by acetone. (Narrow mouth glass bottles have been found to be less prone to leakage.) Alternatively, polyethylene bottles may be used.

6.2.4 Petri Dishes. For filter samples; glass or polyethylene, unless otherwise specified by the Administrator.

6.2.5 Graduated Cylinder and/or Balance. To measure condensed water to within 1 ml or 0.5 g. Graduated cylinders shall have subdivisions no greater than 2 ml.

6.2.6 Plastic Storage Containers. Air-tight containers to store silica gel.

6.2.7 Funnel and Rubber Policeman. To aid in transfer of silica gel to container; not necessary if silica gel is weighed in the field.

6.2.8 Funnel. Glass or polyethylene, to aid in sample recovery.

6.3 Sample Analysis. The following equipment is required for sample analysis:

6.3.1 Glass Weighing Dishes.

6.3.2 Desiccator.

6.3.3 Analytical Balance. To measure to within 0.1 mg.

6.3.4 Balance. To measure to within 0.5 g.

6.3.5 Beakers. 250 ml.

6.3.6 Hygrometer. To measure the relative humidity of the laboratory environment.

6.3.7 Temperature Sensor. To measure the temperature of the laboratory environment.

7.0 Reagents and Standards

7.1 Sample Collection. The following reagents are required for sample collection:

7.1.1 Filters. Glass fiber filters, without organic binder, exhibiting at least 99.95 percent efficiency (<0.05 percent penetration) on 0.3 micron dioctyl phthalate smoke particles. The filter efficiency test shall be conducted in accordance with ASTM Method D 2986-71, 78, or 95a (incorporated by reference—see §60.17). Test data from the supplier's quality control program are sufficient for this purpose. In sources containing SO_2 or SO_3, the filter material must be of a type that is unreactive to SO_2 or SO_3. Reference 10 in section 17.0 may be used to select the appropriate filter.

7.1.2 Silica Gel. Indicating type, 6 to 16 mesh. If previously used, dry at 175 °C (350 °F) for 2 hours. New silica gel may be used as received. Alternatively, other types of desiccants (equivalent or better) may be used, subject to the approval of the Administrator.

7.1.3 Water. When analysis of the material caught in the impingers is required, deionized distilled water [to conform to ASTM D1193-77 or 91 Type 3 (incorporated by reference—see §60.17)] with at least <0.001 percent residue shall be used or as specified in the applicable method requiring analysis of the water. Run reagent blanks prior to field use to eliminate a high blank on test samples.

7.1.4 Crushed Ice.

7.2 Sample Recovery. Acetone, reagent grade, ≤0.001 percent residue, in glass bottles, is required. Acetone from metal containers generally has a high residue blank and should not be used. Sometimes, suppliers transfer acetone to glass bottles from metal containers; thus, acetone blanks shall be run prior to field use and only acetone with low blank values (≤0.001 percent) shall be used. In no case shall a blank value of greater than 0.001 percent of the weight of acetone used be subtracted from the sample weight.

7.3 Sample Analysis. The following reagents are required for sample analysis:

7.3.1 Acetone. Same as in section 7.2.

7.3.2 Desiccant. Anhydrous calcium sulfate, indicating type. Alternatively, other types of desiccants may be used, subject to the approval of the Administrator.

8.0 Sample Collection, Preservation, Storage, and Transport

8.1 Pretest Preparation. It is suggested that sampling equipment be maintained according to the procedures described in APTD-0576. Alternative mercury-free thermometers may be used if the thermometers are at a minimum equivalent in terms of performance or suitably effective for the specific temperature measurement application.

8.1.1 Place 200 to 300 g of silica gel in each of several air-tight containers. Weigh each container, including silica gel, to the nearest 0.5 g, and record this weight. As an alternative, the silica gel need not be preweighed, but may be weighed directly in its impinger or sampling holder just prior to train assembly.

8.1.2 Check filters visually against light for irregularities, flaws, or pinhole leaks. Label filters of the proper diameter on the back side near the edge using numbering machine ink. As an alternative, label the shipping containers (glass or polyethylene petri dishes), and keep each filter in its identified container at all times except during sampling.

8.1.3 Desiccate the filters at 20 ±5.6 °C (68 ±10 °F) and ambient pressure for at least 24 hours. Weigh each filter (or filter and shipping container) at intervals of at least 6 hours to a constant weight (*i.e.*, ≤0.5 mg change from previous weighing). Record results to the nearest 0.1 mg. During each weighing, the period for which the filter is exposed to the laboratory atmosphere shall be less than 2 minutes. Alternatively (unless otherwise specified by the Administrator), the filters may be oven dried at 105 °C (220 °F) for 2 to 3 hours, desiccated for 2 hours, and weighed. Procedures other than those described, which account for relative humidity effects, may be used, subject to the approval of the Administrator.

8.2 Preliminary Determinations.

8.2.1 Select the sampling site and the minimum number of sampling points according to Method 1 or as specified by the Administrator. Determine the stack pressure, temperature, and the range of velocity heads using Method 2; it is recommended that a leak check of the pitot lines (see Method 2, section 8.1) be performed. Determine the moisture content using Approximation Method 4 or its alternatives for the purpose of making isokinetic sampling rate settings. Determine the stack gas dry molecular weight, as described in Method 2, section 8.6; if integrated Method 3 sampling is used for molecular weight determination, the integrated bag sample shall be taken simultaneously with, and for the same total length of time as, the particulate sample run.

8.2.2 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. Ensure that the proper differential pressure gauge is chosen for the range of velocity heads encountered (see section 8.3 of Method 2).

8.2.3 Select a suitable probe liner and probe length such that all traverse points can be sampled. For large stacks, consider sampling from opposite sides of the stack to reduce the required probe length.

8.2.4 Select a total sampling time greater than or equal to the minimum total sampling time specified in the test procedures for the specific industry such that (1) the sampling time per point is not less than 2 minutes (or some greater time interval as specified by the Administrator), and (2) the sample volume taken (corrected to standard conditions) will exceed the required minimum total gas sample volume. The latter is based on an approximate average sampling rate.

8.2.5 The sampling time at each point shall be the same. It is recommended that the number of minutes sampled at each point be an integer or an integer plus one-half minute, in order to avoid timekeeping errors.

8.2.6 In some circumstances (*e.g.*, batch cycles) it may be necessary to sample for shorter times at the traverse points and to obtain smaller gas sample volumes. In these cases, the Administrator's approval must first be obtained.

8.3 Preparation of Sampling Train.

8.3.1 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. Place 100 ml of water in each of the first two impingers, leave the third impinger empty, and transfer approximately 200 to 300 g of preweighed 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. 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.

8.3.2 Using a tweezer or clean disposable surgical gloves, place a labeled (identified) and weighed 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. Check the filter for tears after assembly is completed.

8.3.3 When glass probe liners are used, install the selected nozzle using a Viton A O-ring when stack temperatures are less than 260 °C (500 °F) or a heat-resistant string gasket when temperatures are higher. See APTD-0576 for details. Other connecting systems using either 316 stainless steel or Teflon ferrules may be used. When metal liners are used, install the nozzle as discussed above or by a leak-free direct mechanical connection. Mark the probe with heat resistant tape or by some other method to denote the proper distance into the stack or duct for each sampling point.

8.3.4 Set up the train as shown in Figure 5-1 ensuring that the connections are leak-tight. Subject to the approval of the Administrator, a glass cyclone may be used 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.

8.3.5 Place crushed ice around the impingers.

8.4 Leak-Check Procedures.

8.4.1 Leak Check of Metering System Shown in Figure 5-1. That portion of the sampling train from the pump to the orifice meter should be leak-checked prior to initial use and after each shipment. Leakage after the pump will result in less volume being recorded than is actually sampled. The following procedure is suggested (see Figure 5-2): Close the main valve on the meter box. Insert a one-hole rubber stopper with rubber tubing attached into the orifice exhaust pipe. Disconnect and vent the low side of the orifice manometer. Close off the low side orifice tap. Pressurize the system to 13 to 18 cm (5 to 7 in.) water column by blowing into the rubber tubing. Pinch off the tubing, and observe the manometer for one minute. A loss of pressure on the manometer indicates a leak in the meter box; leaks, if present, must be corrected.

8.4.2 Pretest Leak Check. A pretest leak check of the sampling train is recommended, but not required. If the pretest leak check is conducted, the following procedure should be used.

8.4.2.1 After the sampling train has been assembled, turn on and set the filter and probe heating systems to the desired operating temperatures. Allow time for the temperatures to stabilize. If a Viton A O-ring or other leak-free connection is used in assembling the probe nozzle to the probe liner, leak-check the train at the sampling site by plugging the nozzle and pulling a 380 mm (15 in.) Hg vacuum.

NOTE: A lower vacuum may be used, provided that it is not exceeded during the test.

8.4.2.2 If a heat-resistant string is used, do not connect the probe to the train during the leak check. Instead, leak-check the train by first plugging the inlet to the filter holder (cyclone, if applicable) and pulling a 380 mm (15 in.) Hg vacuum (see note in section 8.4.2.1). Then connect the probe to the train, and leak-check at approximately 25 mm (1 in.) Hg vacuum; alternatively, the probe may be leak-checked with the rest of the sampling train, in one step, at 380 mm (15 in.) Hg vacuum. Leakage rates in excess of 4 percent of the average sampling rate or 0.00057 m^3/min (0.020 cfm), whichever is less, are unacceptable.

8.4.2.3 The following leak-check instructions for the sampling train described in APTD-0576 and APTD-0581 may be helpful. 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.

8.4.2.4 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.

8.4.3 Leak Checks During Sample Run. 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 in section 8.4.2 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 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 as shown in section 12.3 of this method, or void the sample run.

NOTE: Immediately after component changes, leak checks are optional. If such leak checks are done, the procedure outlined in section 8.4.2 above should be used.

8.4.4 Post-Test Leak Check. A leak check of the sampling train is mandatory at the conclusion of each sampling run. The leak check shall be performed in accordance with the procedures

outlined in section 8.4.2, except that it shall 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 as shown in section 12.3 of this method, or void the sampling run.

8.5 Sampling Train Operation. During the sampling run, maintain an isokinetic sampling rate (within 10 percent of true isokinetic unless otherwise specified by the Administrator) and a sample gas temperature through the filter of 120 ± 14 °C (248 ± 25 °F) or such other temperature as specified by an applicable subpart of the standards or approved by the Administrator.

8.5.1 For each run, record the data required on a data sheet such as the one shown in Figure 5-3. 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 readings indicated by Figure 5-3 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.

8.5.2 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. Nomographs are available which aid in the rapid adjustment of the isokinetic sampling rate without excessive computations. These nomographs are designed for use when the Type S pitot tube coefficient (C_p) is 0.85 ±0.02, and the stack gas equivalent density [dry molecular weight (M_d)] is equal to 29 ±4. APTD-0576 details the procedure for using the nomographs. If C_p and M_d are outside the above stated ranges, do not use the nomographs unless appropriate steps (see Reference 7 in section 17.0) are taken to compensate for the deviations.

8.5.3 When the stack is under significant negative pressure (*i.e.,* height of impinger stem), 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.

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

8.5.5 Traverse the stack cross-section, as required by Method 1 or as specified by the Administrator, 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.

8.5.6 During the test run, make periodic adjustments to keep the temperature around the filter holder at the proper level to maintain the sample gas temperature exiting the filter; add more ice and, if necessary, salt to maintain a temperature of less than 20 °C (68 °F) at the condenser/silica gel outlet. Also, periodically check the level and zero of the manometer.

8.5.7 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. It is recommended that another complete filter assembly be used rather than attempting to change the filter itself. Before a new filter assembly is installed, conduct a leak check (see section 8.4.3). The total PM weight shall include the summation of the filter assembly catches.

8.5.8 A single train shall be used for the entire sample run, except in cases where simultaneous sampling is required in two or more separate ducts or at two or more different locations within the same duct, or in cases where equipment failure necessitates a change of trains. In all other situations, the use of two or more trains will be subject to the approval of the Administrator.

NOTE: When two or more trains are used, separate analyses of the front-half and (if applicable) impinger catches from each train shall be performed, unless identical nozzle sizes were used on all trains, in which case, the front-half catches from the individual trains may be combined (as may the impinger catches) and one analysis of front-half catch and one analysis of impinger catch may be performed. Consult with the Administrator for details concerning the calculation of results when two or more trains are used.

8.5.9 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 leak check, as outlined in section 8.4.4. Also, leak-check the pitot lines as described in Method 2, section 8.1. The lines must pass this leak check, in order to validate the velocity head data.

8.6 Calculation of Percent Isokinetic. Calculate percent isokinetic (see Calculations, section 12.11) to determine whether the run was valid or another test run should be made. If there was difficulty in maintaining isokinetic rates because of source conditions, consult with the Administrator for possible variance on the isokinetic rates.

8.7 Sample Recovery.

8.7.1 Proper 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.

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

8.7.3 Before moving the sample train to the cleanup site, remove the probe from the sample train and cap the open outlet of the probe. Be careful not to lose any condensate that might be present. Cap the filter inlet where the probe was fastened. Remove the umbilical cord from the last

impinger, and cap the impinger. If a flexible line is used between the first impinger or condenser and the filter holder, disconnect the line at the filter holder, and let any condensed water or liquid drain into the impingers or condenser. Cap off the filter holder outlet and impinger inlet. Either ground-glass stoppers, plastic caps, or serum caps may be used to close these openings.

8.7.4 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.

8.7.5 Save a portion of the acetone used for cleanup as a blank. From each storage container of acetone used for cleanup, save 200 ml and place in a glass sample container labeled "acetone blank." To minimize any particulate contamination, rinse the wash bottle prior to filling from the tested container.

8.7.6 Inspect the train prior to and during disassembly, and note any abnormal conditions. Treat the samples as follows:

8.7.6.1 Container No. 1. 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 to fold the filter, do so such that the PM cake is inside the fold. Using a dry Nylon bristle brush and/or a sharp-edged blade, carefully transfer to the petri dish any PM and/or filter fibers that adhere to the filter holder gasket. Seal the container.

8.7.6.2 Container No. 2. Taking care to see that dust on the outside of the probe or other exterior surfaces does not get into the sample, quantitatively recover PM or any condensate from the probe nozzle, probe fitting, probe liner, and front half of the filter holder by washing these components with acetone and placing the wash in a glass container. Deionized distilled water may be used instead of acetone when approved by the Administrator and shall be used when specified by the Administrator. In these cases, save a water blank, and follow the Administrator's directions on analysis. Perform the acetone rinse as follows:

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

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

8.7.6.2.3 Rinse the probe liner with acetone by tilting and rotating the probe while squirting acetone into its upper end so that all inside surfaces will be wetted with acetone. Let the acetone 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 acetone rinse with a probe brush. Hold the probe in an inclined position, squirt acetone 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 acetone and particulate matter that is brushed from the probe. Run the brush through the probe three times or more until no visible PM is carried out

with the acetone or until none remains in the probe liner on visual inspection. With stainless steel or other metal probes, run the brush through in the above prescribed manner at least six times since metal probes have small crevices in which particulate matter can be entrapped. Rinse the brush with acetone, and quantitatively collect these washings in the sample container. After the brushing, make a final acetone rinse of the probe.

8.7.6.2.4 It is recommended that two people clean the probe to minimize sample losses. Between sampling runs, keep brushes clean and protected from contamination.

8.7.6.2.5 After ensuring that all joints have been wiped clean of silicone grease, clean the inside of the front half of the filter holder by rubbing the surfaces with a Nylon bristle brush and rinsing with acetone. Rinse each surface three times or more if needed to remove visible particulate. Make a final rinse of the brush and filter holder. Carefully rinse out the glass cyclone, also (if applicable). After all acetone washings and particulate matter have been collected in the sample container, tighten the lid on the sample container so that acetone will not leak out when it is shipped to the laboratory. Mark the height of the fluid level to allow determination of whether leakage occurred during transport. Label the container to identify clearly its contents.

8.7.6.3 Container No. 3. 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. A rubber policeman may be used as an aid in removing the silica gel from the impinger. It is not necessary to remove the small amount of dust particles that may adhere to the impinger wall and are difficult to remove. 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. If a balance is available in the field, follow the procedure for Container No. 3 in section 11.2.3.

8.7.6.4 Impinger Water. Treat the impingers as follows: 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 required (see NOTE, section 6.1.1.8). If a different type of condenser is used, measure the amount of moisture condensed either volumetrically or gravimetrically.

8.8 Sample Transport. Whenever possible, containers should be shipped in such a way that they remain upright at all times.

9.0 Quality Control

9.1 Miscellaneous Quality Control Measures.

Section	Quality control measure	Effect
8.4, 10.1-10.6	Sampling equipment leak check and calibration	Ensures accurate measurement of stack gas flow rate, sample volume.

9.2 Volume Metering System Checks. The following procedures are suggested to check the volume metering system calibration values at the field test site prior to sample collection. These procedures are optional.

9.2.1 Meter Orifice Check. Using the calibration data obtained during the calibration procedure described in section 10.3, determine the ΔH@ for the metering system orifice. The ΔH@ is the orifice pressure differential in units of in. H_2O that correlates to 0.75 cfm of air at 528 °R and 29.92 in. Hg. The ΔH@ is calculated as follows:

$$\Delta H @ = 0.0319\ \Delta H \frac{T_M \theta^2}{P_{bar} Y^2 V_m^2}$$

Where:

ΔH = Average pressure differential across the orifice meter, in. H_2O.

T_m = Absolute average DGM temperature, °R.

P_{bar} = Barometric pressure, in. Hg.

Θ = Total sampling time, min.

Y = DGM calibration factor, dimensionless.

V_m = Volume of gas sample as measured by DGM, dcf.

0.0319 = (0.0567 in. Hg/°R) $(0.75\ cfm)^2$

9.2.1.1 Before beginning the field test (a set of three runs usually constitutes a field test), operate the metering system (*i.e.*, pump, volume meter, and orifice) at the ΔH@ pressure differential for 10 minutes. Record the volume collected, the DGM temperature, and the barometric pressure. Calculate a DGM calibration check value, Y_c, as follows:

$$Y_c = \frac{10}{V_m}\left[\frac{0.0319\ T_m}{P_{bar}}\right]^{\frac{1}{2}}$$

where:

Y_c = DGM calibration check value, dimensionless.

10 = Run time, min.

9.2.1.2 Compare the Y_c value with the dry gas meter calibration factor Y to determine that: $0.97Y < Y_c < 1.03Y$. If the Y_c value is not within this range, the volume metering system should be investigated before beginning the test.

9.2.2 Calibrated Critical Orifice. A critical orifice, calibrated against a wet test meter or spirometer and designed to be inserted at the inlet of the sampling meter box, may be used as a check by following the procedure of section 16.2.

10.0 Calibration and Standardization

NOTE: Maintain a laboratory log of all calibrations.

10.1 Probe Nozzle. Probe nozzles shall be calibrated before their initial use in the field. Using a micrometer, measure the ID of the nozzle to the nearest 0.025 mm (0.001 in.). Make three separate measurements using different diameters each time, and obtain the average of the measurements. The difference between the high and low numbers shall not exceed 0.1 mm (0.004 in.). When nozzles become nicked, dented, or corroded, they shall be reshaped, sharpened, and recalibrated before use. Each nozzle shall be permanently and uniquely identified.

10.2 Pitot Tube Assembly. The Type S pitot tube assembly shall be calibrated according to the procedure outlined in section 10.1 of Method 2.

10.3 Metering System.

10.3.1 Calibration Prior to Use. Before its initial use in the field, the metering system shall be calibrated as follows: Connect the metering system inlet to the outlet of a wet test meter that is accurate to within 1 percent. Refer to Figure 5-4. The wet test meter should have a capacity of 30 liters/rev (1 ft^3/rev). A spirometer of 400 liters (14 ft^3) or more capacity, or equivalent, may be used for this calibration, although a wet test meter is usually more practical. The wet test meter should be periodically calibrated with a spirometer or a liquid displacement meter to ensure the accuracy of the wet test meter. Spirometers or wet test meters of other sizes may be used, provided that the specified accuracies of the procedure are maintained. Run the metering system pump for about 15 minutes with the orifice manometer indicating a median reading as expected in field use to allow the pump to warm up and to permit the interior surface of the wet test meter to be thoroughly wetted. Then, at each of a minimum of three orifice manometer settings, pass an exact quantity of gas through the wet test meter and note the gas volume indicated by the DGM. Also note the barometric pressure and the temperatures of the wet test meter, the inlet of the DGM, and the outlet of the DGM. Select the highest and lowest orifice settings to bracket the expected field operating range of the orifice. Use a minimum volume of 0.14 m^3 (5 ft^3) at all orifice settings. Record all the data on a form similar to Figure 5-5 and calculate Y, the DGM calibration factor, and ΔH , the orifice calibration factor, at each orifice setting as shown on Figure 5-5. Allowable tolerances for individual Y and ΔH values are given in Figure 5-5. Use the average of the Y values in the calculations in section 12.0.

10.3.1.1 Before calibrating the metering system, it is suggested that a leak check be conducted. For metering systems having diaphragm pumps, the normal leak-check procedure will not detect leakages within the pump. For these cases the following leak-check procedure is suggested: make a 10-minute calibration run at 0.00057 m^3/min (0.020 cfm). At the end of the run, take the difference of the measured wet test meter and DGM volumes. Divide the difference by 10 to get the leak rate. The leak rate should not exceed 0.00057 m^3/min (0.020 cfm).

10.3.2 Calibration After Use. After each field use, the calibration of the metering system shall be checked by performing three calibration runs at a single, intermediate orifice setting (based on the previous field test), with the vacuum set at the maximum value reached during the test series. To adjust the vacuum, insert a valve between the wet test meter and the inlet of the metering system. Calculate the average value of the DGM calibration factor. If the value has changed by more than 5 percent, recalibrate the meter over the full range of orifice settings, as detailed in section 10.3.1.

NOTE: Alternative procedures (*e.g.,* rechecking the orifice meter coefficient) may be used, subject to the approval of the Administrator.

10.3.3 Acceptable Variation in Calibration Check. If the DGM coefficient values obtained before and after a test series differ by more than 5 percent, the test series shall either be voided, or calculations for the test series shall be performed using whichever meter coefficient value (*i.e.*, before or after) gives the lower value of total sample volume.

10.4 Probe Heater Calibration. Use a heat source to generate air heated to selected temperatures that approximate those expected to occur in the sources to be sampled. Pass this air through the probe at a typical sample flow rate while measuring the probe inlet and outlet temperatures at various probe heater settings. For each air temperature generated, construct a graph of probe heating system setting versus probe outlet temperature. The procedure outlined in APTD-0576 can also be used. Probes constructed according to APTD-0581 need not be calibrated if the calibration curves in APTD-0576 are used. Also, probes with outlet temperature monitoring capabilities do not require calibration.

NOTE: The probe heating system shall be calibrated before its initial use in the field.

10.5 Temperature Sensors. Use the procedure in Section 10.3 of Method 2 to calibrate in-stack temperature sensors. Dial thermometers, such as are used for the DGM and condenser outlet, shall be calibrated against mercury-in-glass thermometers. An alternative mercury-free NIST-traceable thermometer may be used if the thermometer is, at a minimum, equivalent in terms of performance or suitably effective for the specific temperature measurement application. As an alternative, the following single-point calibration procedure may be used. After each test run series, check the accuracy (and, hence, the calibration) of each thermocouple system at ambient temperature, or any other temperature, within the range specified by the manufacturer, using a reference thermometer (either ASTM reference thermometer or a thermometer that has been calibrated against an ASTM reference thermometer). The temperatures of the thermocouple and reference thermometers shall agree to within ±2 °F.

10.6 Barometer. Calibrate against a mercury barometer or NIST-traceable barometer prior to the field test. Alternatively, barometric pressure may be obtained from a weather report that has been adjusted for the test point (on the stack) elevation.

11.0 Analytical Procedure

11.1 Record the data required on a sheet such as the one shown in Figure 5-6.

11.2 Handle each sample container as follows:

11.2.1 Container No. 1. Leave the contents in the shipping container or transfer the filter and any loose PM from the sample container to a tared glass weighing dish. Desiccate for 24 hours in a desiccator containing anhydrous calcium sulfate. Weigh to a constant weight, and report the results to the nearest 0.1 mg. For the purposes of this section, the term "constant weight" means a difference of no more than 0.5 mg or 1 percent of total weight less tare weight, whichever is greater, between two consecutive weighings, with no less than 6 hours of desiccation time between weighings. Alternatively, the sample may be oven dried at 104 °C (220 °F) for 2 to 3 hours, cooled in the desiccator, and weighed to a constant weight, unless otherwise specified by the Administrator. The sample may be oven dried at 104 °C (220 °F) for 2 to 3 hours. Once the sample has cooled, weigh the sample, and use this weight as a final weight.

11.2.2 Container No. 2. Note the level of liquid in the container, and confirm on the analysis sheet whether leakage occurred during transport. If a noticeable amount of leakage has occurred, either void the sample or use methods, subject to the approval of the Administrator, to correct the final results. Measure the liquid in this container either volumetrically to ±1 ml or gravimetrically to ±0.5 g. Transfer the contents to a tared 250 ml beaker, and evaporate to dryness at ambient temperature and pressure. Desiccate for 24 hours, and weigh to a constant weight. Report the results to the nearest 0.1 mg.

11.2.3 Container No. 3. Weigh the spent silica gel (or silica gel plus impinger) to the nearest 0.5 g using a balance. This step may be conducted in the field.

11.2.4 Acetone Blank Container. Measure the acetone in this container either volumetrically or gravimetrically. Transfer the acetone to a tared 250 ml beaker, and evaporate to dryness at ambient temperature and pressure. Desiccate for 24 hours, and weigh to a constant weight. Report the results to the nearest 0.1 mg.

NOTE: The contents of Container No. 2 as well as the acetone blank container may be evaporated at temperatures higher than ambient. If evaporation is done at an elevated temperature, the temperature must be below the boiling point of the solvent; also, to prevent "bumping," the evaporation process must be closely supervised, and the contents of the beaker must be swirled occasionally to maintain an even temperature. Use extreme care, as acetone is highly flammable and has a low flash point.

12.0 Data Analysis 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 forms of the equations may be used, provided that they give equivalent results.

12.1 Nomenclature.

A_n = Cross-sectional area of nozzle, m^2 (ft^2).

B_{ws} = Water vapor in the gas stream, proportion by volume.

C_a = Acetone blank residue concentration, mg/mg.

c_s = Concentration of particulate matter in stack gas, dry basis, corrected to standard conditions, g/dscm (gr/dscf).

I = Percent of isokinetic sampling.

L_1 = Individual leakage rate observed during the leak-check conducted prior to the first component change, m^3/min (ft^3/min)

L_a = Maximum acceptable leakage rate for either a pretest leak-check or for a leak-check following a component change; equal to 0.00057 m^3/min (0.020 cfm) or 4 percent of the average sampling rate, whichever is less.

L_i = Individual leakage rate observed during the leak-check conducted prior to the "i^{th}" component change (i=1, 2, 3 . . . n), m^3/min (cfm).

L_p = Leakage rate observed during the post-test leak-check, m^3/min (cfm).

m_a = Mass of residue of acetone after evaporation, mg.

m_n = Total amount of particulate matter collected, mg.

M_w = Molecular weight of water, 18.0 g/g-mole (18.0 lb/lb-mole).

P_{bar} = Barometric pressure at the sampling site, mm Hg (in. Hg).

P_s = Absolute stack gas pressure, mm Hg (in. Hg).

P_{std} = Standard absolute pressure, 760 mm Hg (29.92 in. Hg).

R = Ideal gas constant, 0.06236 ((mm Hg)(m^3))/((K)(g-mole)) {21.85 ((in. Hg) (ft^3))/((°R) (lb-mole))}.

T_m = Absolute average DGM temperature (see Figure 5-3), K (°R).

T_s = Absolute average stack gas temperature (see Figure 5-3), K (°R).

T_{std} = Standard absolute temperature, 293 K (528 °R).

V_a = Volume of acetone blank, ml.

V_{aw} = Volume of acetone used in wash, ml.

V_{lc} = Total volume of liquid collected in impingers and silica gel (see Figure 5-6), ml.

V_m = Volume of gas sample as measured by dry gas meter, dcm (dcf).

$V_{m(std)}$ = Volume of gas sample measured by the dry gas meter, corrected to standard conditions, dscm (dscf).

$V_{w(std)}$ = Volume of water vapor in the gas sample, corrected to standard conditions, scm (scf).

V_s = Stack gas velocity, calculated by Method 2, Equation 2-7, using data obtained from Method 5, m/sec (ft/sec).

W_a = Weight of residue in acetone wash, mg.

Y = Dry gas meter calibration factor.

ΔH = Average pressure differential across the orifice meter (see Figure 5-4), mm H_2O (in. H_2O).

ρ_a = Density of acetone, mg/ml (see label on bottle).

ρ_w = Density of water, 0.9982 g/ml. (0.002201 lb/ml).

θ = Total sampling time, min.

θ_1 =Sampling time interval, from the beginning of a run until the first component change, min.

θ_i= Sampling time interval, between two successive component changes, beginning with the interval between the first and second changes, min.

θ_p = Sampling time interval, from the final (n^{th}) component change until the end of the sampling run, min.

13.6 = Specific gravity of mercury.

60 = Sec/min.

100 = Conversion to percent.

12.2 Average Dry Gas Meter Temperature and Average Orifice Pressure Drop. See data sheet (Figure 5-3).

12.3 Dry Gas Volume. Correct the sample volume measured by the dry gas meter to standard conditions (20 °C, 760 mm Hg or 68 °F, 29.92 in. Hg) by using Equation 5-1.

$$V_{m(std)} = V_m Y \frac{T_{std}\left(P_{bar} + \frac{\Delta H}{13.6}\right)}{T_m P_{std}} \qquad Eq.\ 5\text{-}1$$

$$= K_1 V_m Y \frac{P_{bar} + \left(\frac{\Delta H}{13.6}\right)}{T_m}$$

Where:

K_1 = 0.3858 °K/mm Hg for metric units, = 17.64 °R/in. Hg for English units.

NOTE: Equation 5-1 can be used as written unless the leakage rate observed during any of the mandatory leak checks (*i.e.*, the post-test leak check or leak checks conducted prior to

component changes) exceeds L_a. If L_p or L_i exceeds L_a, Equation 5-1 must be modified as follows:

(a) Case I. No component changes made during sampling run. In this case, replace V_m in Equation 5-1 with the expression:

$$\left(V_m - \left(L_p - L_a\right)\theta\right)$$

(b) Case II. One or more component changes made during the sampling run. In this case, replace V_m in Equation 5-1 by the expression:

$$\left[V_m - \left(L_1 - L_a\right)\theta_1 - \sum_{i=2}^{n}\left(L_i - L_a\right)\theta_i - \left(L_p - L_a\right)\theta_p\right]$$

and substitute only for those leakage rates (L_i or L_p) which exceed L_a.

12.4 Volume of Water Vapor Condensed.

$$V_{w(std)} = V_{lc}\frac{\rho_w R T_{std}}{M_w P_{std}} \qquad \text{Eq. 5-2}$$

$$= K_2 V_{lc}$$

Where:

$K_2 = 0.001333$ m^3/ml for metric units, $= 0.04706$ ft^3/ml for English units.

12.5 Moisture Content.

$$B_{ws} = \frac{V_{w(std)}}{V_{m(std)} + V_{w(std)}} \qquad \text{Eq. 5-3}$$

NOTE: In saturated or water droplet-laden gas streams, two calculations of the moisture content of the stack gas shall be made, one from the impinger analysis (Equation 5-3), and a second from the assumption of saturated conditions. The lower of the two values of B_{ws} shall be considered correct. The procedure for determining the moisture content based upon the assumption of saturated conditions is given in section 4.0 of Method 4. For the purposes of this method, the average stack gas temperature from Figure 5-3 may be used to make this determination, provided that the accuracy of the in-stack temperature sensor is ±1 °C (2 °F).

12.6 Acetone Blank Concentration.

$$C_a = \frac{m_a}{V_a \rho_a} \qquad \text{Eq. 5-4}$$

12.7 Acetone Wash Blank.

$$W_a = C_a V_{aw} \rho_a \qquad \text{Eq. 5-5}$$

12.8 Total Particulate Weight. Determine the total particulate matter catch from the sum of the weights obtained from Containers 1 and 2 less the acetone blank (see Figure 5-6).

NOTE: In no case shall a blank value of greater than 0.001 percent of the weight of acetone used be subtracted from the sample weight. Refer to section 8.5.8 to assist in calculation of results involving two or more filter assemblies or two or more sampling trains.

12.9 Particulate Concentration.

$$C_s = \frac{K_3 m_a}{V_{m(std)}} \qquad \text{Eq. 5-6}$$

Where:

K_3 = 0.001 g/mg for metric units.

= 0.0154 gr/mg for English units.

12.10 Conversion Factors:

From	To	Multiply by
ft^3	m^3	0.02832
gr	mg	64.80004
gr/ft^3	mg/m^3	2288.4
mg	g	0.001
gr	lb	1.429×10^{-4}

12.11 Isokinetic Variation.

12.11.1 Calculation from Raw Data.

$$I = \frac{100 T_s \left[K_4 V_{lc} + \frac{(V_m Y)}{T_m} \left(P_{bar} + \frac{\Delta H}{13.6} \right) \right]}{60 \theta v_s P_s A_n} \qquad \text{Eq. 5-7}$$

Where:

$K_4 = 0.003454$ ((mm Hg)(m^3))/((ml)(°K)) for metric units,

$= 0.002669$ ((in. Hg)(ft^3))/((ml)(°R)) for English units.

12.11.2 Calculation from Intermediate Values.

$$I = \frac{T_s V_{m(std)} P_{std} 100}{T_{std} v_s \theta A_n P_s 60 (1 - B_{ws})} \qquad \text{Eq. 5-8}$$

$$= K_5 \frac{T_s V_{m(std)}}{P_s v_s A_n \theta (1 - B_{ws})}$$

Where:

$K_5 = 4.320$ for metric units,

$= 0.09450$ for English units.

12.11.3 Acceptable Results. If 90 percent $\leq I \leq 110$ percent, the results are acceptable. If the PM results are low in comparison to the standard, and "I" is over 110 percent or less than 90 percent, the Administrator may opt to accept the results. Reference 4 in section 17.0 may be used to make acceptability judgments. If "I" is judged to be unacceptable, reject the results, and repeat the sampling run.

12.12 Stack Gas Velocity and Volumetric Flow Rate. Calculate the average stack gas velocity and volumetric flow rate, if needed, using data obtained in this method and the equations in sections 12.3 and 12.4 of Method 2.

13.0 Method Performance [Reserved]

14.0 Pollution Prevention [Reserved]

15.0 Waste Management [Reserved]

16.0 Alternative Procedures

16.1 Dry Gas Meter as a Calibration Standard. A DGM may be used as a calibration standard for volume measurements in place of the wet test meter specified in section 10.3, provided that it is calibrated initially and recalibrated periodically as follows:

16.1.1 Standard Dry Gas Meter Calibration.

16.1.1.1. The DGM to be calibrated and used as a secondary reference meter should be of high quality and have an appropriately sized capacity (*e.g.*, 3 liters/rev (0.1 ft^3/rev)). A spirometer (400 liters (14 ft^3) or more capacity), or equivalent, may be used for this calibration, although a wet test meter is usually more practical. The wet test meter should have a capacity of 30 liters/rev (1 ft^3/rev) and capable of measuring volume to within 1.0 percent. Wet test meters should be checked against a spirometer or a liquid displacement meter to ensure the accuracy of the wet test meter. Spirometers or wet test meters of other sizes may be used, provided that the specified accuracies of the procedure are maintained.

16.1.1.2 Set up the components as shown in Figure 5-7. A spirometer, or equivalent, may be used in place of the wet test meter in the system. Run the pump for at least 5 minutes at a flow rate of about 10 liters/min (0.35 cfm) to condition the interior surface of the wet test meter. The pressure drop indicated by the manometer at the inlet side of the DGM should be minimized (no greater than 100 mm H_2O (4 in. H_2O) at a flow rate of 30 liters/min (1 cfm)). This can be accomplished by using large diameter tubing connections and straight pipe fittings.

16.1.1.3 Collect the data as shown in the example data sheet (see Figure 5-8). Make triplicate runs at each of the flow rates and at no less than five different flow rates. The range of flow rates should be between 10 and 34 liters/min (0.35 and 1.2 cfm) or over the expected operating range.

16.1.1.4 Calculate flow rate, Q, for each run using the wet test meter volume, V_W, and the run time, θ. Calculate the DGM coefficient, Y_{ds}, for each run. These calculations are as follows:

$$Q = K_1 \frac{P_{bar} V_w}{(T_w + T_{std})\theta} \qquad \text{Eq. 5-9}$$

$$Y_{ds} = \frac{V_w (T_{ds} + T_{std}) P_{bar}}{V_{ds} (T_w + T_{std}) \left(P_{bar} + \frac{\Delta p}{13.6} \right)} \qquad \text{Eq. 5-10}$$

Where:

K_1 = 0.3858 °C/mm Hg for metric units=17.64 °F/in. Hg for English units.

V_W = Wet test meter volume, liter (ft^3).

V_{ds} = Dry gas meter volume, liter (ft^3).

T_{ds} = Average dry gas meter temperature, °C ((°deg;F).

T_{adj} = 273 °C for metric units, = 460 °F for English units.

T_W = Average wet test meter temperature, °C ((°deg;F)

P_{bar} = Barometric pressure, mm Hg (in. Hg).

Δp = Dry gas meter inlet differential pressure, mm H_2O (in. H_2O).

Θ = Run time, min.

16.1.1.5 Compare the three Y_{ds} values at each of the flow rates and determine the maximum and minimum values. The difference between the maximum and minimum values at each flow rate should be no greater than 0.030. Extra sets of triplicate runs may be made in order to complete this requirement. In addition, the meter coefficients should be between 0.95 and 1.05. If these specifications cannot be met in three sets of successive triplicate runs, the meter is not suitable as a calibration standard and should not be used as such. If these specifications are met, average the three Y_{ds} values at each flow rate resulting in no less than five average meter coefficients, Y_{ds}.

16.1.1.6 Prepare a curve of meter coefficient, Y_{ds}, versus flow rate, Q, for the DGM. This curve shall be used as a reference when the meter is used to calibrate other DGMs and to determine whether recalibration is required.

16.1.2 Standard Dry Gas Meter Recalibration.

16.1.2.1 Recalibrate the standard DGM against a wet test meter or spirometer annually or after every 200 hours of operation, whichever comes first. This requirement is valid provided the standard DGM is kept in a laboratory and, if transported, cared for as any other laboratory instrument. Abuse to the standard meter may cause a change in the calibration and will require more frequent recalibrations.

16.1.2.2 As an alternative to full recalibration, a two-point calibration check may be made. Follow the same procedure and equipment arrangement as for a full recalibration, but run the meter at only two flow rates [suggested rates are 14 and 30 liters/min (0.5 and 1.0 cfm)]. Calculate the meter coefficients for these two points, and compare the values with the meter calibration curve. If the two coefficients are within 1.5 percent of the calibration curve values at the same flow rates, the meter need not be recalibrated until the next date for a recalibration check.

16.2 Critical Orifices As Calibration Standards. Critical orifices may be used as calibration standards in place of the wet test meter specified in section 16.1, provided that they are selected, calibrated, and used as follows:

16.2.1 Selection of Critical Orifices.

16.2.1.1 The procedure that follows describes the use of hypodermic needles or stainless steel needle tubings which have been found suitable for use as critical orifices. Other materials and critical orifice designs may be used provided the orifices act as true critical orifices (*i.e.*, a critical vacuum can be obtained, as described in section 16.2.2.2.3). Select five critical orifices that are appropriately sized to cover the range of flow rates between 10 and 34 liters/min (0.35 and 1.2 cfm) or the expected operating range. Two of the critical orifices should bracket the expected operating range. A minimum of three critical orifices will be needed to calibrate a

Method 5 DGM; the other two critical orifices can serve as spares and provide better selection for bracketing the range of operating flow rates. The needle sizes and tubing lengths shown in Table 5-1 in section 18.0 give the approximate flow rates.

16.2.1.2 These needles can be adapted to a Method 5 type sampling train as follows: Insert a serum bottle stopper, 13 by 20 mm sleeve type, into a ½ -inch Swagelok (or equivalent) quick connect. Insert the needle into the stopper as shown in Figure 5-9.

16.2.2 Critical Orifice Calibration. The procedure described in this section uses the Method 5 meter box configuration with a DGM as described in section 6.1.1.9 to calibrate the critical orifices. Other schemes may be used, subject to the approval of the Administrator.

16.2.2.1 Calibration of Meter Box. The critical orifices must be calibrated in the same configuration as they will be used (*i.e.*, there should be no connections to the inlet of the orifice).

16.2.2.1.1 Before calibrating the meter box, leak check the system as follows: Fully open the coarse adjust valve, and completely close the by-pass valve. Plug the inlet. Then turn on the pump, and determine whether there is any leakage. The leakage rate shall be zero (*i.e.*, no detectable movement of the DGM dial shall be seen for 1 minute).

16.2.2.1.2 Check also for leakages in that portion of the sampling train between the pump and the orifice meter. See section 8.4.1 for the procedure; make any corrections, if necessary. If leakage is detected, check for cracked gaskets, loose fittings, worn O-rings, etc., and make the necessary repairs.

16.2.2.1.3 After determining that the meter box is leakless, calibrate the meter box according to the procedure given in section 10.3. Make sure that the wet test meter meets the requirements stated in section 16.1.1.1. Check the water level in the wet test meter. Record the DGM calibration factor, Y.

16.2.2.2 Calibration of Critical Orifices. Set up the apparatus as shown in Figure 5-10.

16.2.2.2.1 Allow a warm-up time of 15 minutes. This step is important to equilibrate the temperature conditions through the DGM.

16.2.2.2.2 Leak check the system as in section 16.2.2.1.1. The leakage rate shall be zero.

16.2.2.2.3 Before calibrating the critical orifice, determine its suitability and the appropriate operating vacuum as follows: Turn on the pump, fully open the coarse adjust valve, and adjust the by-pass valve to give a vacuum reading corresponding to about half of atmospheric pressure. Observe the meter box orifice manometer reading, ΔH. Slowly increase the vacuum reading until a stable reading is obtained on the meter box orifice manometer. Record the critical vacuum for each orifice. Orifices that do not reach a critical value shall not be used.

16.2.2.2.4 Obtain the barometric pressure using a barometer as described in section 6.1.2. Record the barometric pressure, P_{bar}, in mm Hg (in. Hg).

16.2.2.2.5 Conduct duplicate runs at a vacuum of 25 to 50 mm Hg (1 to 2 in. Hg) above the critical vacuum. The runs shall be at least 5 minutes each. The DGM volume readings shall be in increments of complete revolutions of the DGM. As a guideline, the times should not differ by more than 3.0 seconds (this includes allowance for changes in the DGM temperatures) to achieve ±0.5 percent in K′ (see Eq. 5-11). Record the information listed in Figure 5-11.

16.2.2.2.6 Calculate K′ using Equation 5-11.

$$K' = \frac{K_1 V_m Y \left[P_{bar} + \frac{\Delta H}{13.6} \right] T_{amb}^{1/2}}{P_{bar} T_m \theta} \qquad \text{Eq. 5-11}$$

Where:

K′ = Critical orifice coefficient,

$[m^3)(°K)^{1}/_{2}]$/

[(mm Hg)(min)] {$[(ft^3)(°R)^{1}/_{2})]$ [(in. Hg)(min)].

T_{amb} = Absolute ambient temperature, °K (°R).

Calculate the arithmetic mean of the K′ values. The individual K' values should not differ by more than ±0.5 percent from the mean value.

16.2.3 Using the Critical Orifices as Calibration Standards.

16.2.3.1 Record the barometric pressure.

16.2.3.2 Calibrate the metering system according to the procedure outlined in section 16.2.2. Record the information listed in Figure 5-12.

16.2.3.3 Calculate the standard volumes of air passed through the DGM and the critical orifices, and calculate the DGM calibration factor, Y, using the equations below:

$$V_{m(std)} = \frac{K_1 V_m \left[P_{bar} + \left(\frac{\Delta H}{13.6} \right) \right]}{T_m} \qquad \text{Eq. 5-12}$$

$$V_{cr(std)} = K' \frac{P_{bar} \theta}{\sqrt{T_{amb}}} \qquad \text{Eq. 5-13}$$

$$Y = \frac{V_{cr\,(std)}}{V_{m(std)}} \qquad \text{Eq. 5-14}$$

Where:

$V_{cr(std)}$ = Volume of gas sample passed through the critical orifice, corrected to standard conditions, dscm (dscf).

K_1 = 0.3858 K/mm Hg for metric units

= 17.64 °R/in. Hg for English units.

16.2.3.4 Average the DGM calibration values for each of the flow rates. The calibration factor, Y, at each of the flow rates should not differ by more than ±2 percent from the average.

16.2.3.5 To determine the need for recalibrating the critical orifices, compare the DGM Y factors obtained from two adjacent orifices each time a DGM is calibrated; for example, when checking orifice 13/2.5, use orifices 12/10.2 and 13/5.1. If any critical orifice yields a DGM Y factor differing by more than 2 percent from the others, recalibrate the critical orifice according to section 16.2.2.

16.3 Alternative Post-Test Metering System Calibration. The following procedure may be used as an alternative to the post-test calibration described in Section 10.3.2. This alternative procedure does not detect leakages between the inlet of the metering system and the dry gas meter. Therefore, two steps must be included to make it an equivalent alternative:

(1) The metering system must pass the post-test leak-check from either the inlet of the sampling train or the inlet of the metering system. Therefore, if the train fails the former leak-check, another leak-check from the inlet of the metering system must be conducted;

(2) The metering system must pass the leak-check of that portion of the train from the pump to the orifice meter as described in Section 8.4.1.

16.3.1 After each test run, do the following:

16.3.1.1 Ensure that the metering system has passed the post-test leak-check. If not, conduct a leak-check of the metering system from its inlet.

16.3.1.2 Conduct the leak-check of that portion of the train from the pump to the orifice meter as described in Section 10.3.1.1.

16.3.1.3 Calculate Y_{qa} for each test run using the following equation:

$$Y_{qa} = \frac{\theta}{V_m}\sqrt{\frac{0.03191 T_m}{\Delta H@\left(P_{bar} + \frac{\Delta H_{avg}}{13.6}\right)}\left(\frac{29}{M_d}\right)}\left(\sqrt{\Delta H}\right)_{avg} \qquad \text{Eq. 5-15}$$

Where:

Y_{qa} = Dry gas meter calibration check value, dimensionless.

$0.0319 = (29.92/528)\ (0.75)^2$ (in. Hg/°R) cfm^2.

$\Delta H@$ = Orifice meter calibration coefficient, in. H_2O.

M_d = Dry molecular weight of stack gas, lb/lb-mole.

29 = Dry molecular weight of air, lb/lb-mole.

16.3.2 After each test run series, do the following:

16.3.2.1 Average the three or more Y_{qa}'s obtained from the test run series and compare this average Y_{qa} with the dry gas meter calibration factor Y. The average Y_{qa} must be within 5 percent of Y.

16.3.2.2 If the average Y_{qa} does not meet the 5 percent criterion, recalibrate the meter over the full range of orifice settings as detailed in Section 10.3.1. Then follow the procedure in Section 10.3.3.

17.0 References.

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11. Westlin, P.R. and R.T. Shigehara. Procedure for Calibrating and Using Dry Gas Volume Meters as Calibration Standards. Source Evaluation Society Newsletter. 3(1):17-30. February 1978.

12. Lodge, J.P., Jr., J.B. Pate, B.E. Ammons, and G.A. Swanson. The Use of Hypodermic Needles as Critical Orifices in Air Sampling. J. Air Pollution Control Association. *16*:197-200. 1966.

13. Shigehara, Roger T., P.G. Royals, and E.W. Steward. "Alternative Method 5 Post-Test Calibration." Entropy Incorporated, Research Triangle Park, NC 27709.

18.0 Tables, Diagrams, Flowcharts, and Validation Data

TABLE 5-1 FLOR RATES FOR VARIOUS NEEDLE SIZES AND TUBE LENGTHS

Gauge/cm	Flow rate liters/min.	Gauge/cm	Flow rate liters/min.
12/7.6	32.56	14/2.5	19.54
12/10.2	30.02	14/5.1	17.27
13/2.5	25.77	14/7.6	16.14
13/5.1	23.50	15/3.2	14.16
13/7.6	22.37	15/7.6	11.61
13/10.2	20.67	15/10.2	10.48

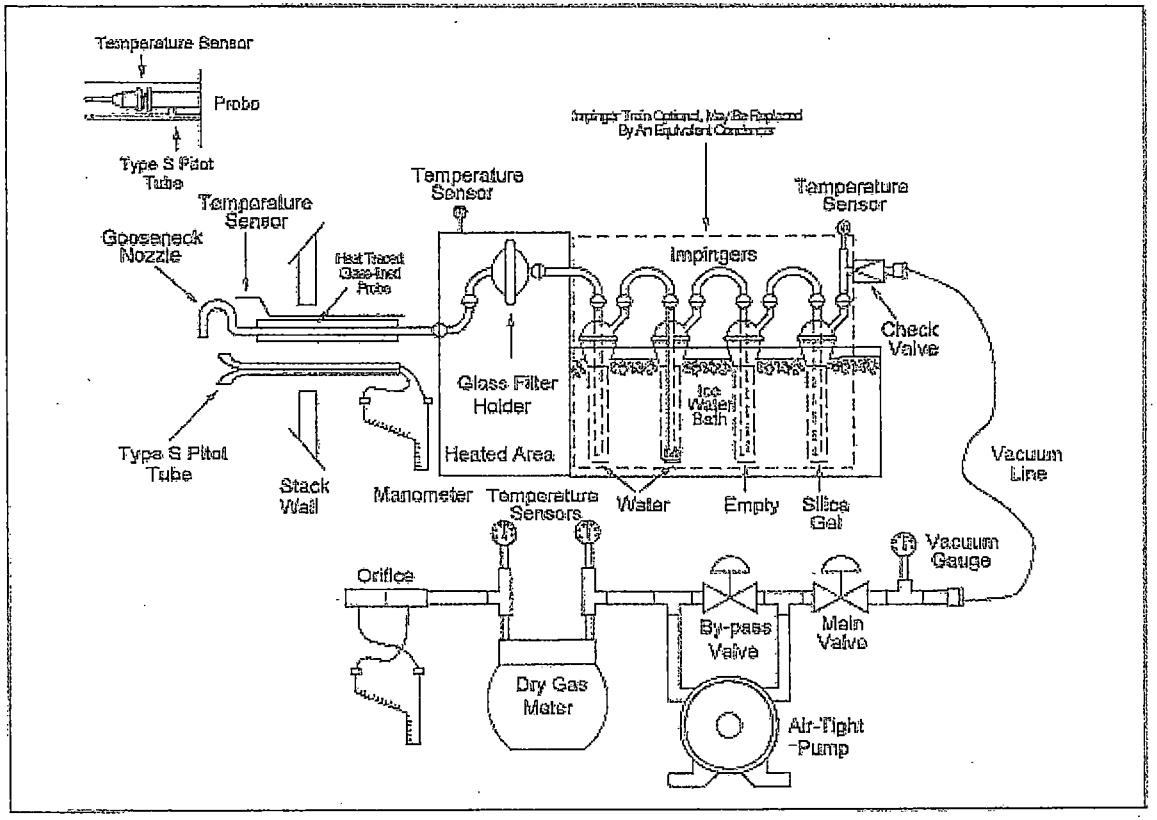


Figure 5-1. Particulate Sampling Train.

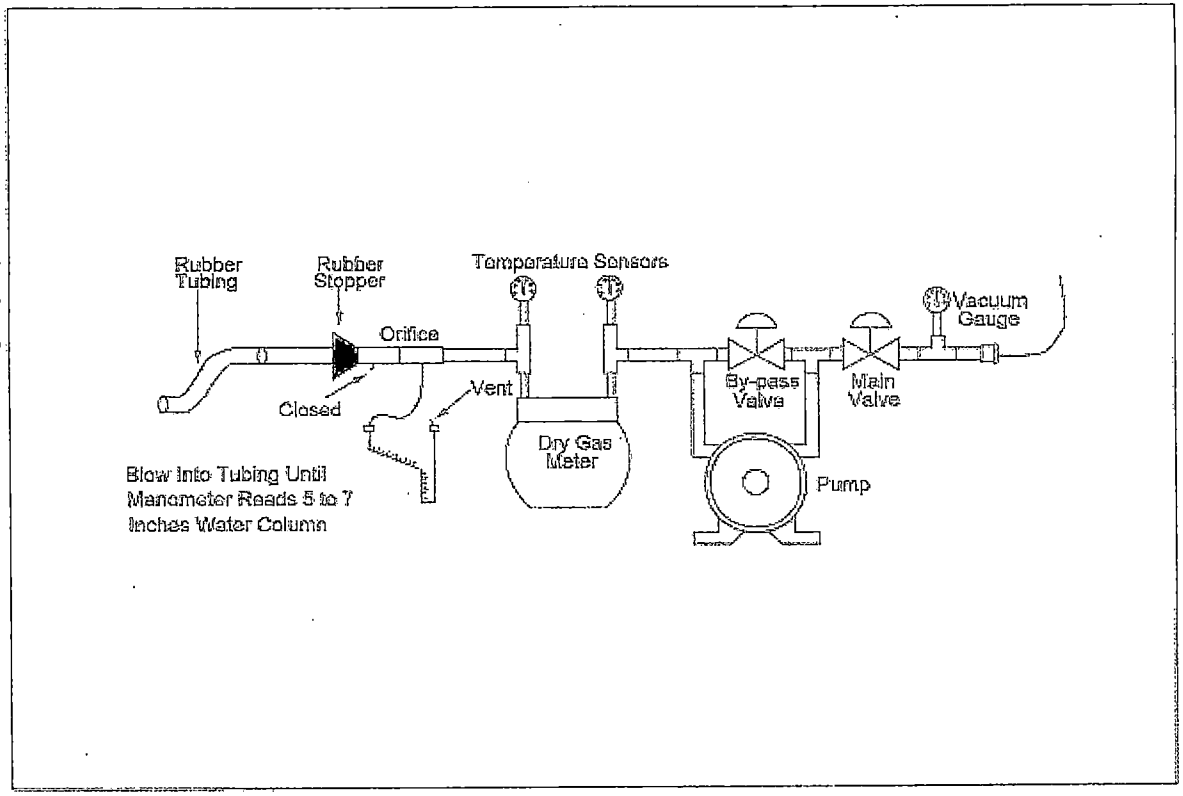
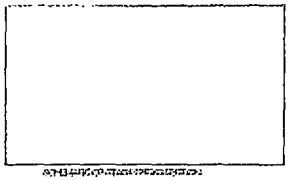


Figure 5-2. Leak Check of Meter Box.

Figure 5-3. Particulate field data.

Plant _____
Location _____
Operator _____
Date _____
Run No. _____
Sample Box No. _____
Meter box No. _____
Meter $\Delta H@$ _____
Orifice _____
Pitot tube coefficient, C_p _____



Ambient temperature _____
Barometric pressure _____
Assumed moisture, % _____
Probe length, (ft) _____
Nozzle identification No. _____
Average calibrated nozzle diameter, (in.) _____
Probe heater setting _____
Leak rate, (cfm) _____
Static pressure (in. H_2O) _____
Filter No. _____

Traverse point number	Sampling time (min.)	Vacuum (in. Hg)	Stack temperature (T_s) (°F)	Velocity head (ΔP_s) (in. H_2O)	Pressure differential across orifice meter (in. H_2O)	Gas meter reading (ft³)	Gas sample temperature at dry gas meter: Inlet (°F)	Gas sample temperature at dry gas meter: Outlet (°F)	Filter temperature (°F)	Temperature of gas leaving condenser or last impinger (°F)
Total							Avg	Avg		
Average							Avg			

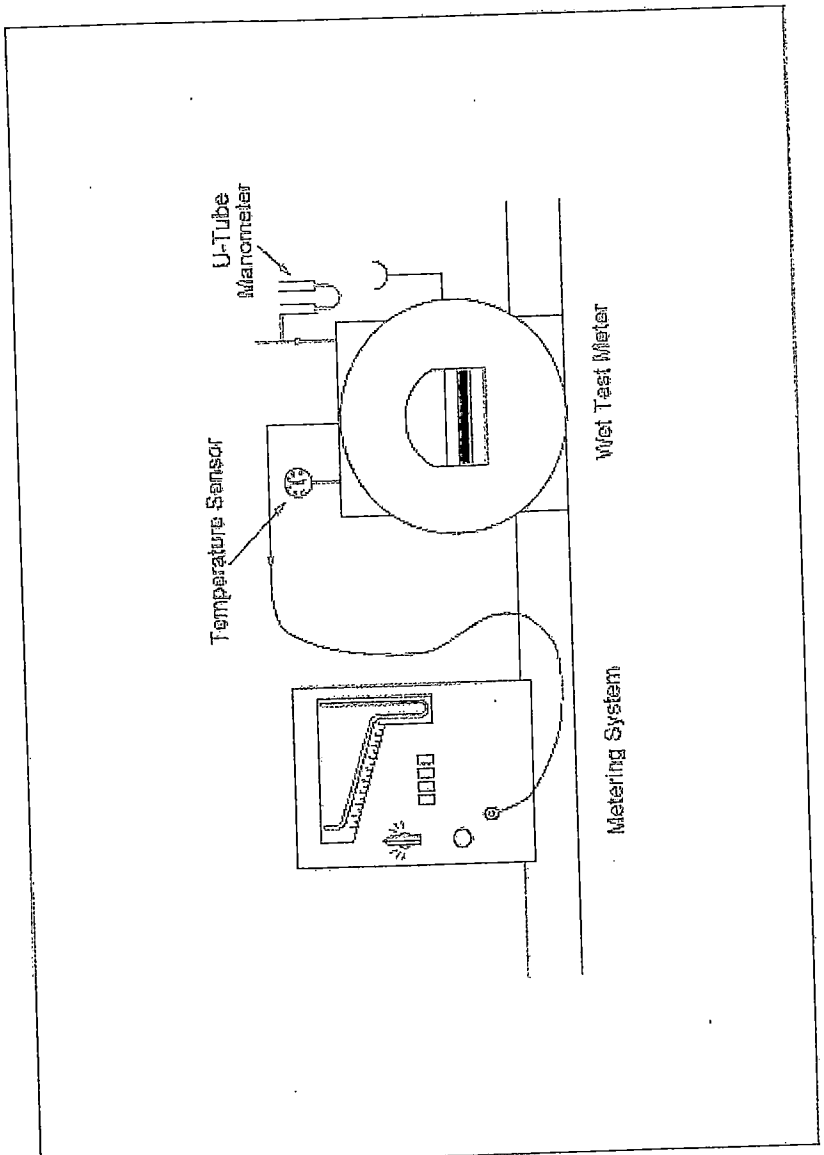


Figure 5-4. Equipment arrangement for metering system calibration.

Figure 5-5. Example Data Sheet for Calibration of Metering System (Laboratory Data).

Date: _____ Metering System Identification: _____

Barometric pressure, P_b = _____ in. Hg

Orifice manometer setting ΔH, in. H_2O	Spirometer (wet meter) gas volume, V_w, ft³	Dry gas meter volume, V_d, ft³	Temperatures: Spirometer (wet meter) T_w, °F	Temperatures: Dry Gas Meter, Inlet T_i, °F	Temperatures: Dry Gas Meter, Outlet T_o, °F	Temperatures: Dry Gas Meter, Average T_d, °F	Time θ, min

Calculations

ΔH, in H_2O	Y				$\Delta H@$		
Average							

Y = Ratio of reading of wet test meter to dry test meter; tolerance for individual values ± 0.02 from average.

$\Delta H_@$ = Orifice pressure differential that equates to 0.75 cfm of air @ 68°F and 29.92 inches of mercury, in. H_2O; tolerance for individual values ± 0.20 from average

Plant_____
Date _____
Run No. _____
Filter No. _____
Amount liquid lost during transport _____
Acetone blank volume, ml_____
Acetone blank concentration, mg/mg (Equation 5-4) _____
Acetone wash blank, mg (Equation 5-5) _____

Container number	Weight of particulate collected, mg		
	Final weight	Tare weight	Weight gain
1.			
2.			
Total:			
Less acetone blank			
Weight of particulate matter			
	Volume of liquid water collected		
	Impinger volume, ml	Silica gel weight, g	
Final			
Initial			
Liquid collected			
Total volume collected		g*	ml

*Convert weight of water to volume by dividing total weight increase by density of water (1 g/ml).

Figure 5-6. Analytical Data Sheet

$$\frac{Increase,\ g}{(1g\ /\ ml)} = \text{Volume water, ml}$$

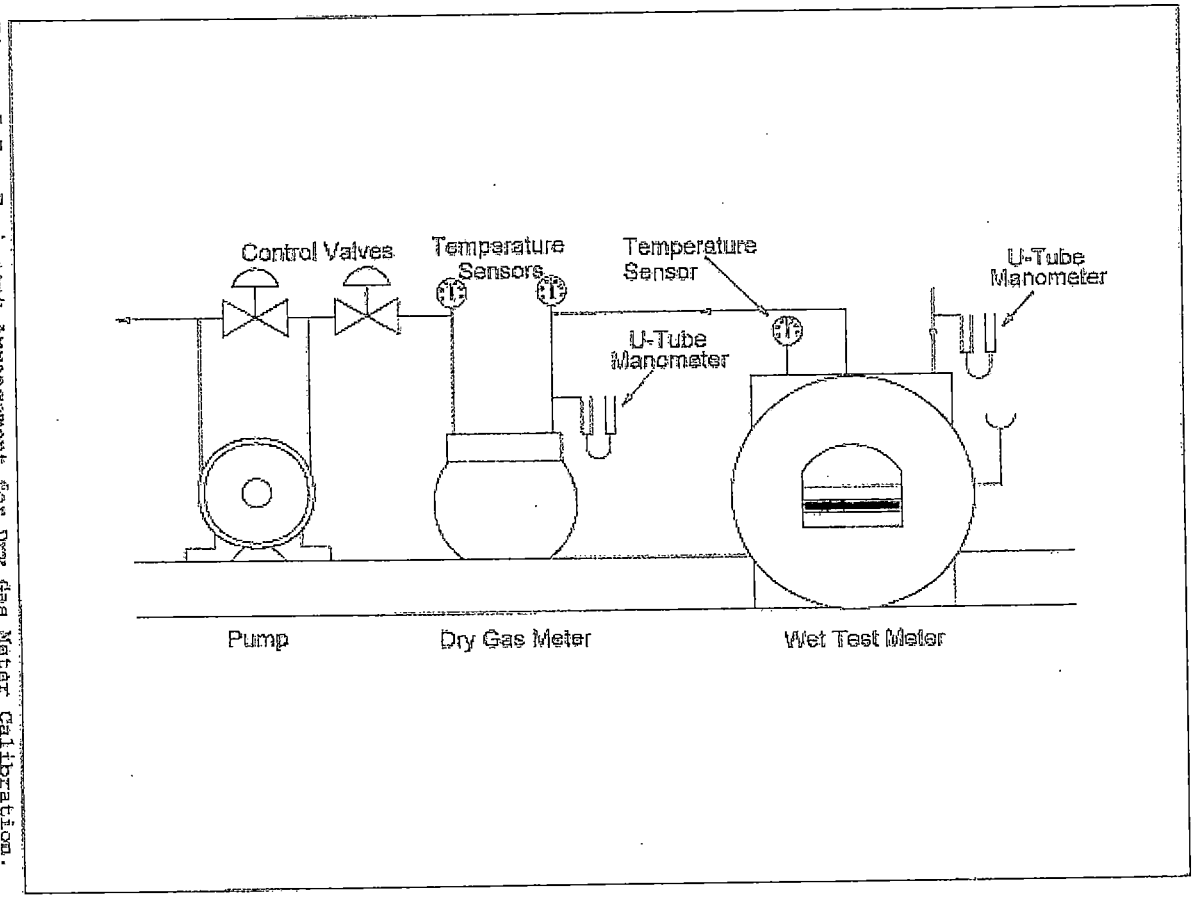


Figure 5-7. Equipment Arrangement for Dry Gas Meter Calibration.

Figure 5-8. Example Data Sheet for Calibration of a Standard Dry Gas Meter for Method 5 Sampling Equipment (English units).

Date: _____

Dry Gas Meter Identification: _____

Barometric Pressure (P_b): _____ in. Hg

Approximate Flow Rate ($\bar{Q}$) cfm	Spirometer (Wet Meter) Gas Volume (V_s) ft³	Dry Gas Meter Volume (V_{dg}) ft³	Temperatures: Spirometer (Wet Meter) (t_s) °F	Temperatures: Dry Gas Meter Inlet (t_i) °F	Temperatures: Dry Gas Meter Outlet (t_o) °F	Temperatures: Dry Gas Meter Average ($\bar{t}_d$) °F	Dry Gas Meter Pressure (Δp) in. H_2O	Time (θ) min	Flow Rate (Q) cfm	Meter Coefficient (Y_{ds})	Average Meter Coefficient ($\overline{Y_{ds}}$)
0.40											
0.60											
0.80											
1.00											
1.20											

$$Q = K_1 \frac{P_{bar} V_w}{(T_w + T_{std}\,\theta)}$$

$$Y_{ds} = \frac{V_w (T_{ds} + T_{std}) P_{bar}}{V_{ds} (T_w + T_{std}) (P_{bar} + \Delta P/13.6)}$$

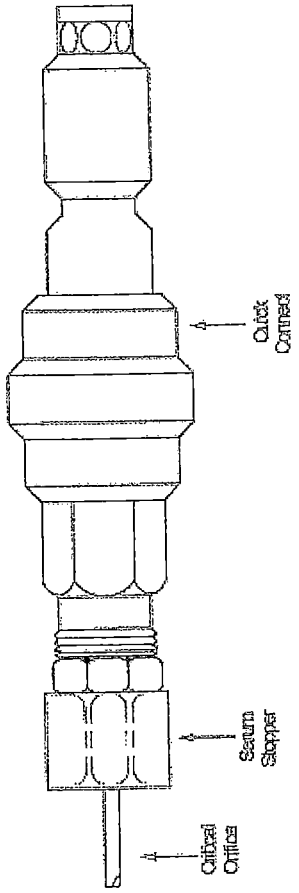


Figure 5-9. Critical Orifice Adaptation to Method 5 Metering System.

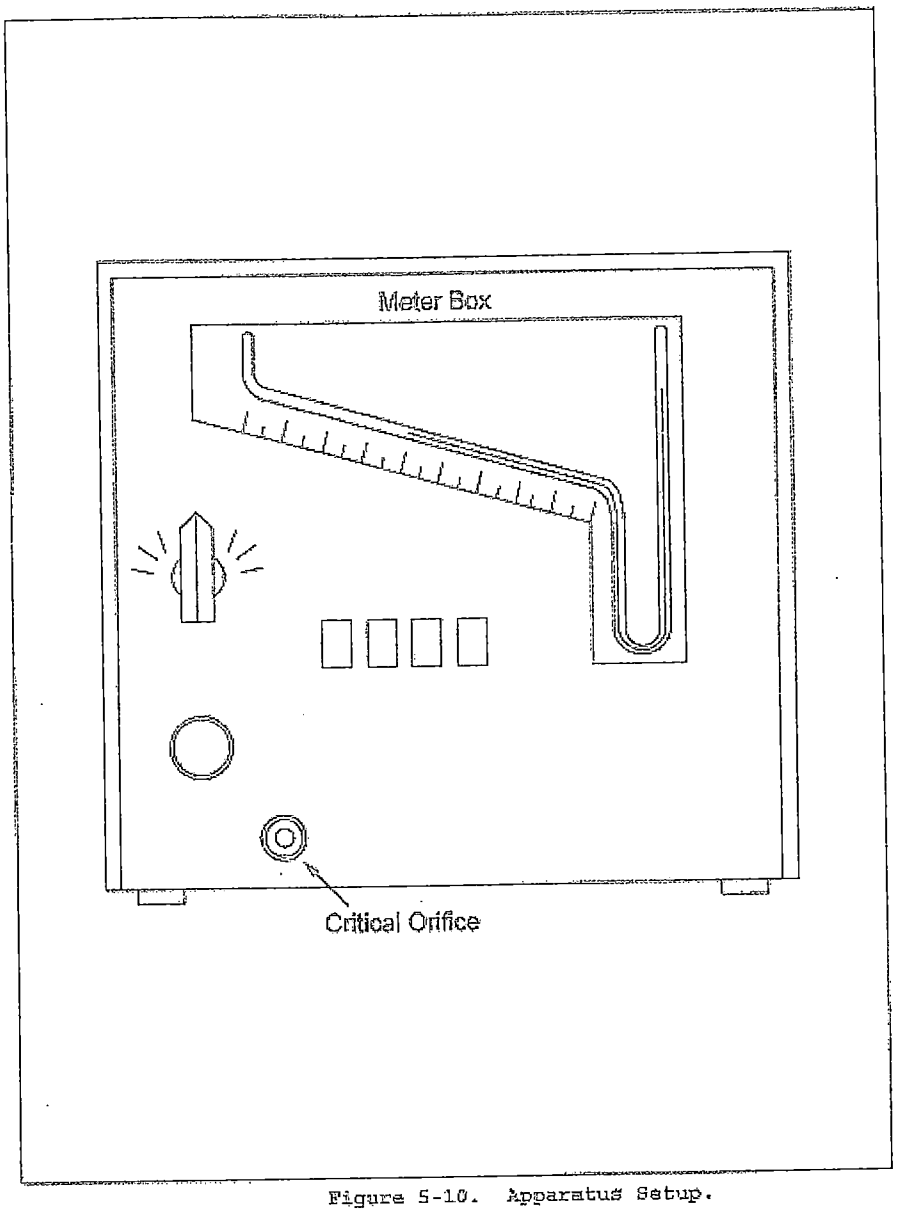


Figure 5-10. Apparatus Setup.

Date _____
Train ID _____
DGM cal. Factor _____
Critical orifice ID_____

Dry gas meter		Run No. 1	2
Final reading	m^3 (ft^3)		
Initial reading	m^3 (ft^3)		
Difference, V^m	m^3 (ft^3)		
Inlet/Outlet			
Temperatures:	°C ((°deg;F)	/	/
Initial	°C ((°deg;F)	/	/
Final	min/sec	/	/
Av. Temeperature, t_m	min		
Time, θ			
Orifice man. rdg., ΔH	mm (in.) H_2		
Bar. pressure, P^{bar}	mm (in.) Hg		
Ambient temperature, t_{amb}	mm (in.) Hg		
Pump vacuum			
K′ factor			
Average			

Figure 5-11. Data sheet of determining K′ factor.

Date _____
Train ID _____
Critical orifice ID _____
Critical orifice K' factor _____

Dry gas meter		Run No. 1	Run No. 2
Final reading	m^3 (ft^3)		
Initial reading	m^3 (ft^3)		
Difference, V_m	m^3 (ft^3)		
Inlet/outlet temperatures	°C ((°deg;F)	/	/
Initial	°C ((°deg;F)	/	/
Final	°C ((°deg;F)		
Avg. Temperature, t_m	min/sec	/	/
Time, θ	min		
Orifice man. rdg., ΔH	min		
Bar. pressure, P_{bar}	mm (in.) H_2O		
Ambient temperature, t_{amb}	mm (in.) Hg		
Pump vacuum	°C ((°deg;F)		
$V_{m(std)}$	mm (in.) Hg		
$V_{cr(std)}$	m^3 (ft^3)		
DGM cal. factor, Y	m^3 (ft^3)		

Figure 5-12. Data Sheet for Determining DGM Y Factor

APPENDIX 2

LANDAUER NORDIC

High-Sensitivity radon measurements with passive alpha-track detectors

LANDAUER NORDIC AB

Tryggve Rönnqvist, Technical Manager (PhD in Nuclear Physics)

June 6. 2016

LANDAUER NORDIC

About Landauer Nordic AB

1986-2009
The company (former Gammadata Mätteknik AB) was founded when a group of researchers from Uppsala University was given a directive from the Swedish government to take charge of the **measurements of caesium in food and crops** in Sweden after the Chernobyl disaster in Ukraine. In 1989 the company expanded its business area to include **radon measurements of indoor air**.

2009-2015
Part of the US company Landauer Inc.

2015-
New owner: Lagercrantz Group AB (Sweden).
The former US radon operation in Landauer Inc. is part of Landauer Nordic AB.

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Quality and experience

The laboratory is accredited to the ISO 17025 standard by SWEDAC and accredited to the NELAP standard by the state of New York and the laboratory is certified by AARST/NRPP (107831 AL) and CARST/CNRPP (CRT 201475).

Landauer Nordic is also certified according to the quality and environmental standards ISO 9001 and ISO 14001.

Since the start, the laboratory has analysed more than 3'000'000 passive radon detectors in more than 40 different countries.

The present yearly detector production is about:

- Radtrak2 long-term – 250'000-300'000 detectors
- Rapidos short-term and HS – 15'000 detectors (5%).

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High-Sensitivity Measurements

The following items are most important for measurements of very low radon concentrations with passive alpha-track radon detectors:

- **Alpha-track film material with very low "material background".**
- **New detector top parts to minimize background growth form long-lived radon decay products in the detector top part.**
- **Large read area on the CR-39 film to improve counting statistics**
- **High sensitivity so that the signal to background ratio is as large as possible.**

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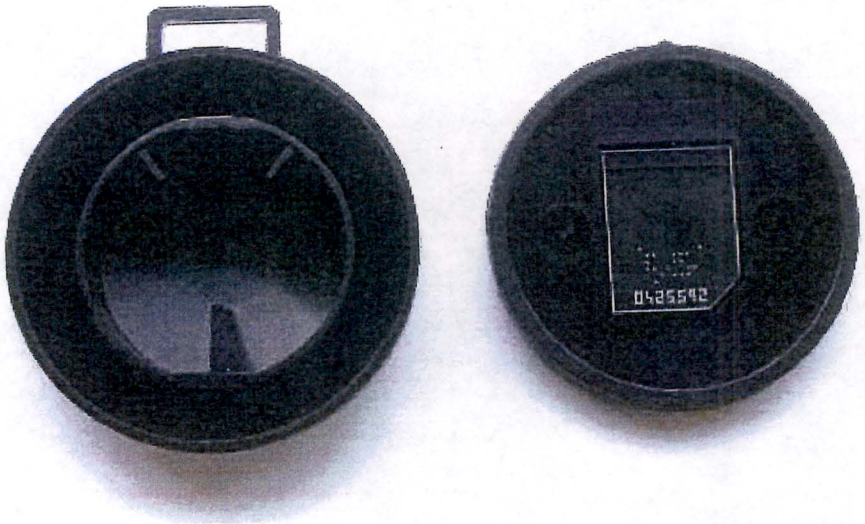
Radtrak2
Long-Term Radon Measurements

Radon gas enters the detector through the small gap between the bottom and top of the detector holder. No radon decay products can enter the detector from the outside (filter).

Measurement period at least 3 months.

Diffusion time: about 25 minutes



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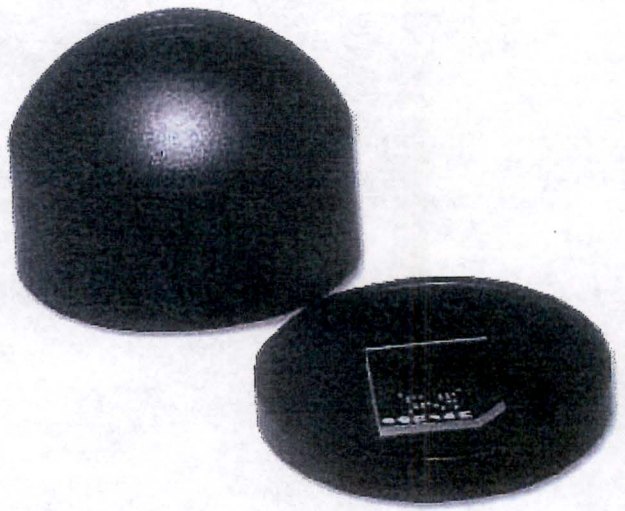
RAPIDOS
Short-Term Radon Measurements

Larger detector holder (RAPIDOS) provides better counting statistics and a better signal to background relation.

Measurement period at least 7 days (usually 10 days).

Are also used in High-Sensitivity applications (out-door measurements)



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CR-39 Material Handling

- From a CR-39 manufacturing process (batch), 20-40 CR-39 sheets can be created.
- From each sheet, about 120 2x2.5 cm^2 films can be created.
- For each sheet, 6 films are cut out for quality control of the plastic. The best plastic is selected for the Rapidos detectors. During 2015-2016 30% of the approved sheets passed the Rapidos quality requirements.
- From the manufactured detectors to a sheet, 3 detectors are used for calibration. The calibration factor is set for a batch of CR-39 films, about 2000-4000 films.
- From the manufactured detectors to a sheet, 6 detectors are used to determine the background. The background is set for each sheet of CR-39 films, about 100-120 films.

To do accurate low-exposure measurements, a low background with a low observed standard deviation is needed.

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Sensitivity and Measured Area

Detector	Sensitivity (tracks/cm^2 per pCi-d/L)	Measure area (cm^2)
Radtrak	2.8	0.37
Radtrak HS	2.8	0.68
Radtrak2	2.3	1.40
Rapidos	4.6	1.40
Rapidos HS	4.6	2.25

For the Rapidos and Radtrak2 measurements, 49 subareas are measured in the microscope system. For the Rapidos HS, 79 subareas are measured on each film. Checks are made on the different subareas to identify possible quality problems on the film.

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Decay of U-238

Isotope	Half life		Main decay	Comment
U-238	**$4{,}5 \cdot 10^9$**	**years**	**α**	
Th-234	24,1	days	β	
Pa-234	1,17	minutes	β	
U-234	$2{,}47 \cdot 10^5$	years	α	
Th-230	$8{,}0 \cdot 10^4$	years	α	
Ra-226	1 620	years	α	
Rn-222	**3,823**	**days**	**α**	**Gas**
Po-218	3,05	minutes	α	"Radon daughters"
Pb-214	26,8	minutes	β, γ	short lived
Bi-214	19,7	minutes	β, γ	
Po-214	$1{,}6 \cdot 10^{-4}$	seconds	α	
Pb-210	21,3	years	β	Long lived
Bi-210	5,01	days	β	"radon daughters"
Po-210	138,4	days	α	
Pb-206	stable			

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Background Growth

The increase in background with time is measured through analyzing non-exposed old detectors (on-year old, two-year old). This will give an background growth factor which for a 30 days storage is about:

- Old Radtrak – 3.5 pCi-d/L (as presented by Landauer Inc, April 2013)
- Radtrak2 - 3.3 pCi-d/L (present correction)
- Rapidos - 1.5 pCi-d/L (present correction)

The numbers above for Radtrak2 and Rapidos are based on the complete stock of detector parts. The "half-life" of detector parts is estimated to be 3 years (Radtrak2).
With present stock of Rapidos parts with new logotype, the age is maximum 1.5 years giving an estimated background aging factor < 1.0 pCi-d/L.

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Lowest Level of Detection (LLD)

According to EPA 402-R-95-012 the Lowest Level of Detection (LLD) should be calculated as:
LLD = $4.65*\sigma_b$ where σ_b is the standard deviation for the observed background.

In the ISO 11655-4 standard, the LLD calculations are based on the background level and not the standard deviation which will give a lower estimate of the LLD

Average background data (2014) from 2200 Radtrak2 sheets and 110 Rapidos sheets:

- Radtrak2 – 45 ± 12 counts (σ_b 80% higher than SQRT(counts))
- Rapidos – 27 ± 8 counts (σ_b 50% higher than SQRT(counts))

Background is not purely statistical due to material artifacts. A LLD estimate based on background standard deviation is more correct.

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Lowest Level of Detection (LLD)

Detector	LLD-average (pCi-d/L)	LLD+2σ_{LLD} (pCi-d/L)	LLD+2σ_{LLD} (pCi/L)
Radtrak2	19.9	37.8	
Rapidos	6.5	11.0	
Rapidos HS	5.1	8.7	
Rapidos HS (1 month)	5.5	9.1	0.30
Rapidos HS (2 month)	5.9	9.5	0.16
Rapidos HS (3 month)	6.3	9.9	0.11

The Rapidos HS background growth uncertainty for 30 day period is assumed to be 0.4 pCi-d/L based on our best assessment.

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Transit Control Kit Detectors

A kit with 3 Rapidos HS is used for the return transport. The radon-proof bags of the transport detectors are opened when the HS detectors should be returned for analysis.

The transport detectors:

- measure the transit exposure
- Receive the same background growth due to long-lived radon progeny as the measurement detectors.

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Performance Data

Landauer Radon Inc. in Westmont is using Lab Transport Kits (standard Rapidos) for the return shipment to Landauer Nordic in Sweden. The data for the return transports (about 40) made are:

- Average transport exposure: 4.1 pCi-d/l
- Average transport standard deviation: 2.4 pCi-d/l

The precision of the Rapidos detector were tested (2012/2013) in type tests at the Bowser-Morner laboratory and in the radon chamber at Landauer Inc. The lowest LLD for Rapidos detectors is set to 10 pCi-d/L.

Radon chamber	Exposure (pCi-d/L)	%Bias	%CV
Bowser-Morner	20.1	-2.5	8.1
Bowser-Morner	49.9	-5.7	4.8
Landauer Inc.	25	-3.8	5.8

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Outdoor Protecting Canister

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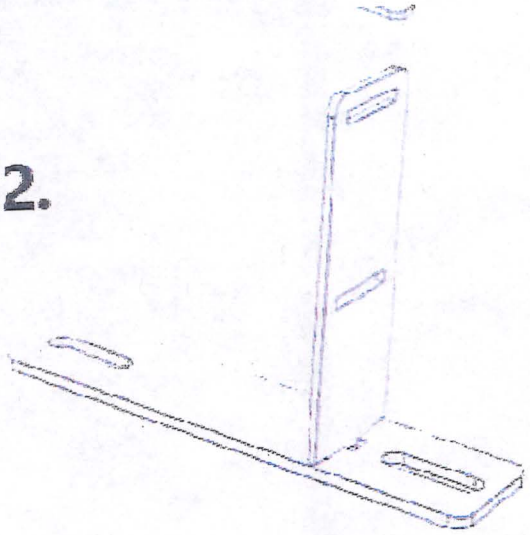
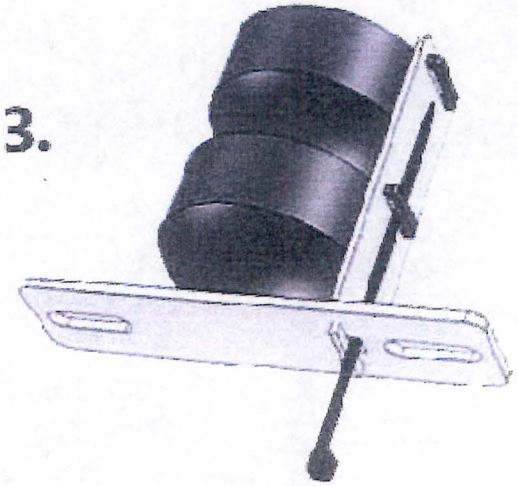
Mounting in Protective Canister via Outdoor Assembly Kit

2.



3.



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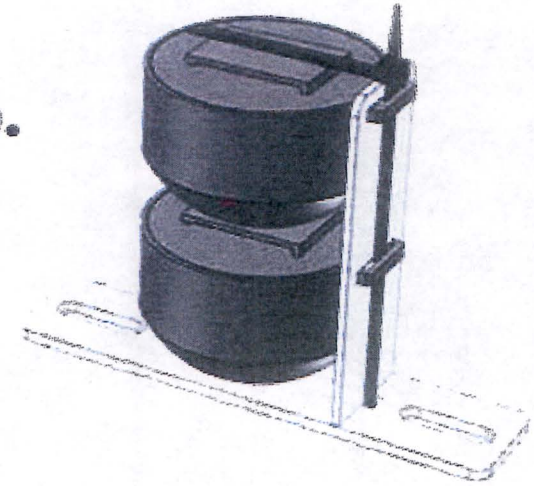

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Thank you !

www.landauerradon.com

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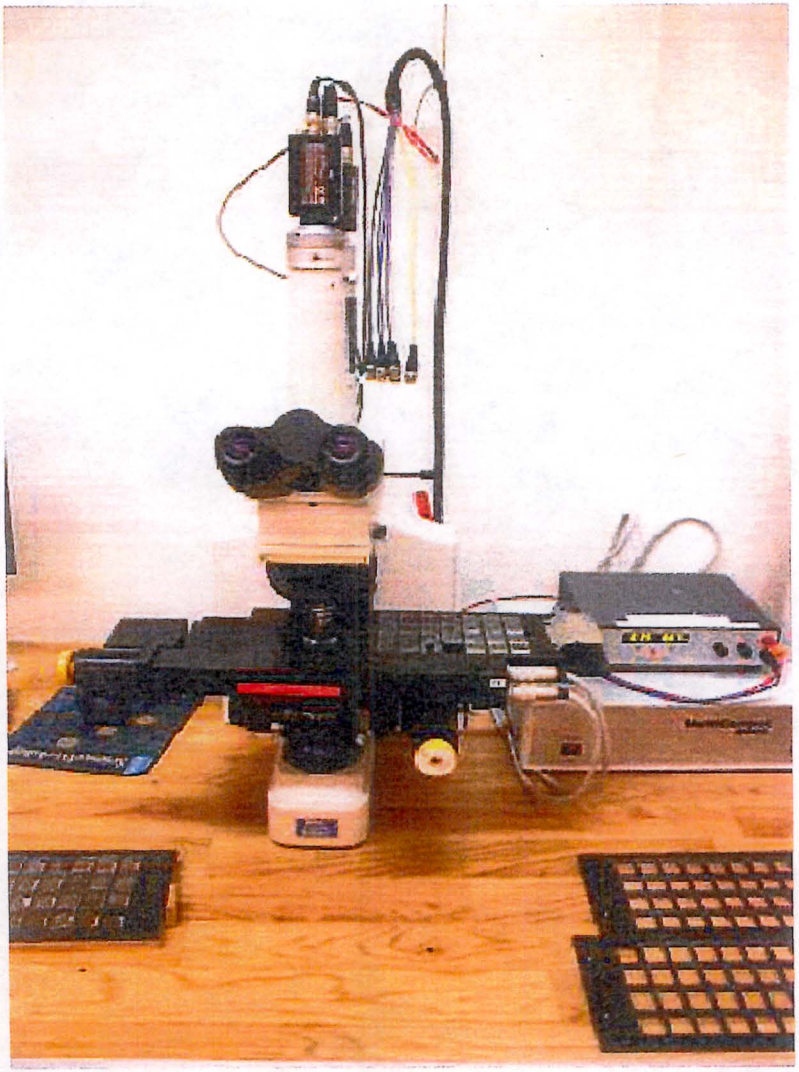
Extra

The following slides are not part of the presentation but could be shown when questions are made.

LANDAUER NORDIC

GammaRad – nuclear track reading system



Total measured area: 1.4 cm^2

Measured subareas: 49

Large focus depth: +/- 0.2 mm

Automatic film number reading

Film measuring speed: 20 s

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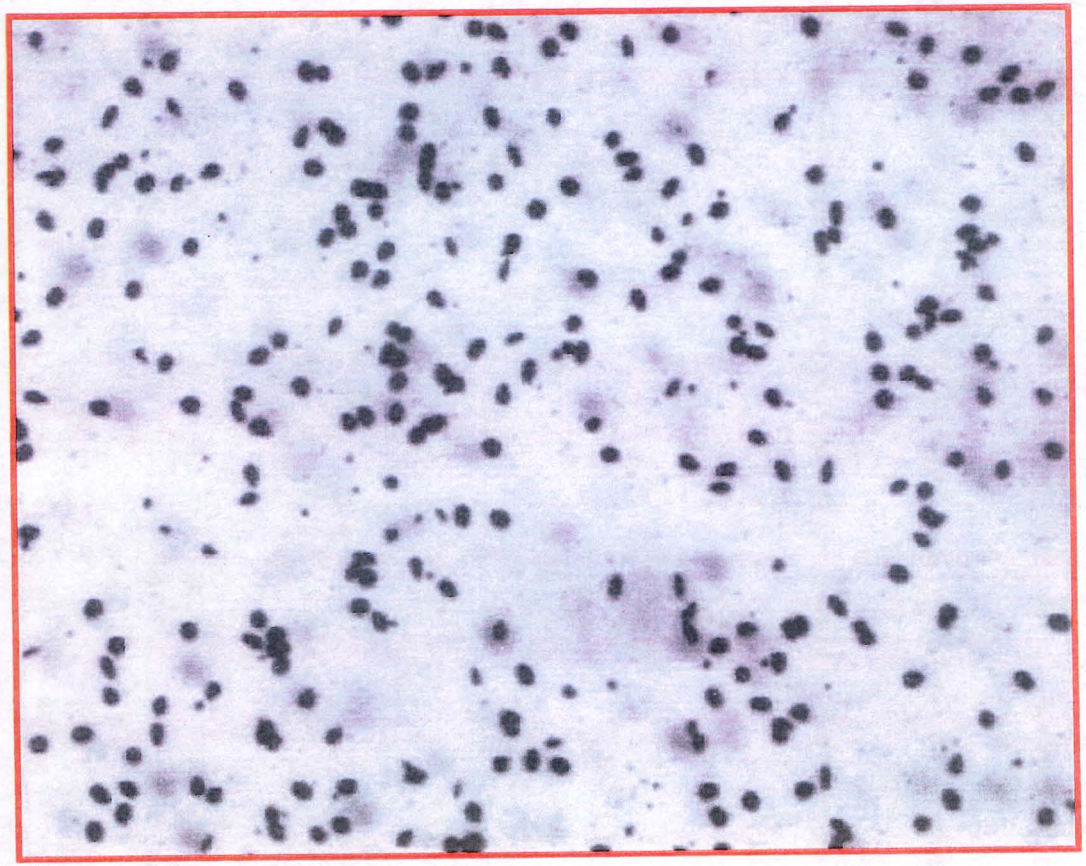
Radon tracks



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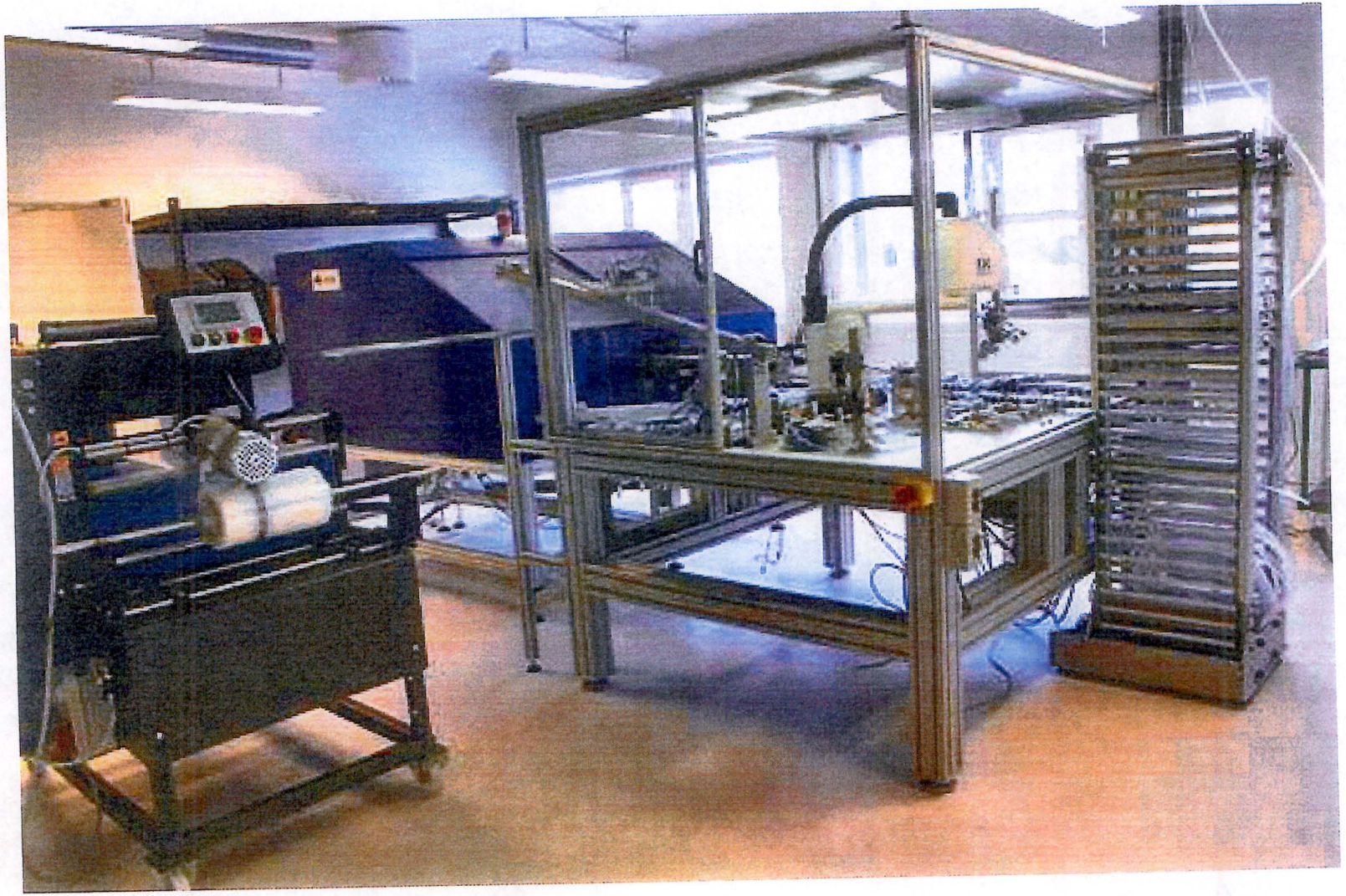
Detector production – robot cell

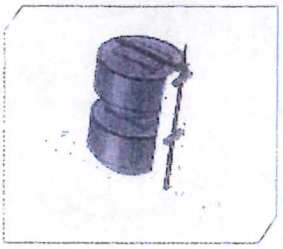


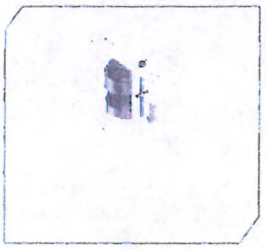
APPENDIX 3

LANDAUER®
RADON

Rapidos
A High-Sensitivity Detector

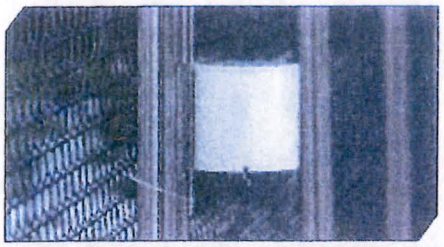
Rapidos High Sensitivity Detectors offer the opportunity to measure very low concentrations of radon gas--for example in connection with environmental outdoor measurements, mining and prospecting for uranium. The detectors are also suitable for surveys of houses and buildings in areas where a very low radon concentration is indicated.





Alpha track detector for low concentrations

- Detector consists of a film element located within a pod made from a special antistatic plastic
- Radon enters into the detector by diffusion - non thoron sensitive
- Analysis is performed using a state-of-the-art image scanner
- Transit control detectors allow the accurate measurement of only the radon level present at the survey site
- Additional specially designed Protective Cannister is available for outdoor applications



Technical Specifications

Detector Application	High Sensitivity Detector
Lowest Detection Limit (Bq/m³)	10 Bqm⁻³ at 1 month measurement 5 Bqm⁻³ at 2 month measurement 4 Bqm⁻³ at 3 month measurement or longer
Normal Exposure Duration	1 - 3 months
Uncertainty (%)	15% at 224 kBqh/m³ (3 month at 10 Bq/m³)
Basis of Uncertainty	1 sd
Detector Sensitivity (tracks cm⁻² kBq⁻¹h⁻¹m³)	4.4
Typical Background (kBqh/m⁻³)	4
Standard Deviation on Background (kBq h m⁻³)	1
Detector Diameter (mm)	58 (63.5 with hanger)
Detector Height (mm)	40 (43 with dip)
Detector Holder Type	Closed, with filter
Detector Holder Design	Rapidos own, black
Detector Holder Antistatic Measures	Conducting holder
Detector Material	CR39/PADC

LANDAUER®
RADON

The global leader in radon measurement

LANDAUER RADON is a pioneer in radon detection, having manufactured and analyzed alpha track detectors for more than 30 years. Our devices are used globally by a broad spectrum of users including scientifically astute, industry-leading practitioners. LANDAUER RADON's measurement methods are accredited by SWEDAC (Swedish Board of Accreditation and Conformity Assessment) to the ISO17025 standard using the measurement protocols of the EPA (Environmental Protection Agency), HPA (Health Protection Agency, UK) and SSM (Swedish Radiation Protection Institute. LANDAUER RADON's laboratory is accredited by NRPP (National Radon Proficiency Program) and C-NRPP (Canadian National Radon Proficiency Program).

Corporate Office: 900 Oakmont Lane, Suite 207 Westmont, IL 60559 www.landauerradon.com T: 331 814 2200 F: 331 814 2214 help@landauerradon.com

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Outdoor Assembly Kit Instructions

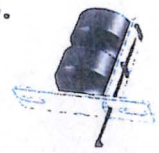
The Rapidos High Sensitivity Outdoor Environmental detector is designed to fit within our existing proprietary Protective Canister via an Outdoor Assembly Kit, included with the purchase of this service. A single Protective Canister can now accommodate 1 or 2 detectors for easy duplicate measurements. See assembly steps below.

1.

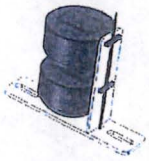
The Outdoor Assembly Kit includes two plastic brackets and two zip ties used to attach Rapidos devices into Protective Canisters.

2.

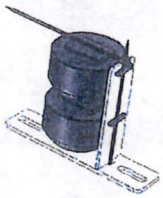
Fit the brackets together loosely, placing the notch of part A into small rectangle opening in part B.

3. 

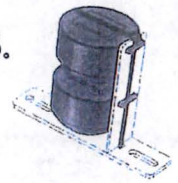
Insert the tab(s) on the detector(s) through the rectangular slots in part A. Insert the first zip tie through part B and detector tabs.

4. 

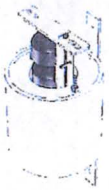
Push the zip tie all the way through part B and inside detector tab(s), securing detector(s) to part A.

5. 

Affix the second zip tie to the end of the first zip tie, locking parts A and B together.

6. 

Cut excess from the second zip tie so the entire kit will fit in the Protective Canister.

7. 

Insert the assembled kit into the Protective Canister aligning the slots in part B to Protective Canister's existing bolts.

8.

Use Protective Canister wing nuts to secure assembled kit inside canister.

9.

Do not over tighten wing nuts when securing assembled kit as it may cause bracket to crack.

When returning detectors for analysis, disassemble and separate detectors from kit by cutting the zip tie. Return only the detectors, not the Assembly Kit or Protective Canister. Like the canister, the plastic brackets can be reused.

Return Detectors To:
Landauer Radon, Inc.
900 Oakmont Lane Suite 207
Westmont, IL 60559

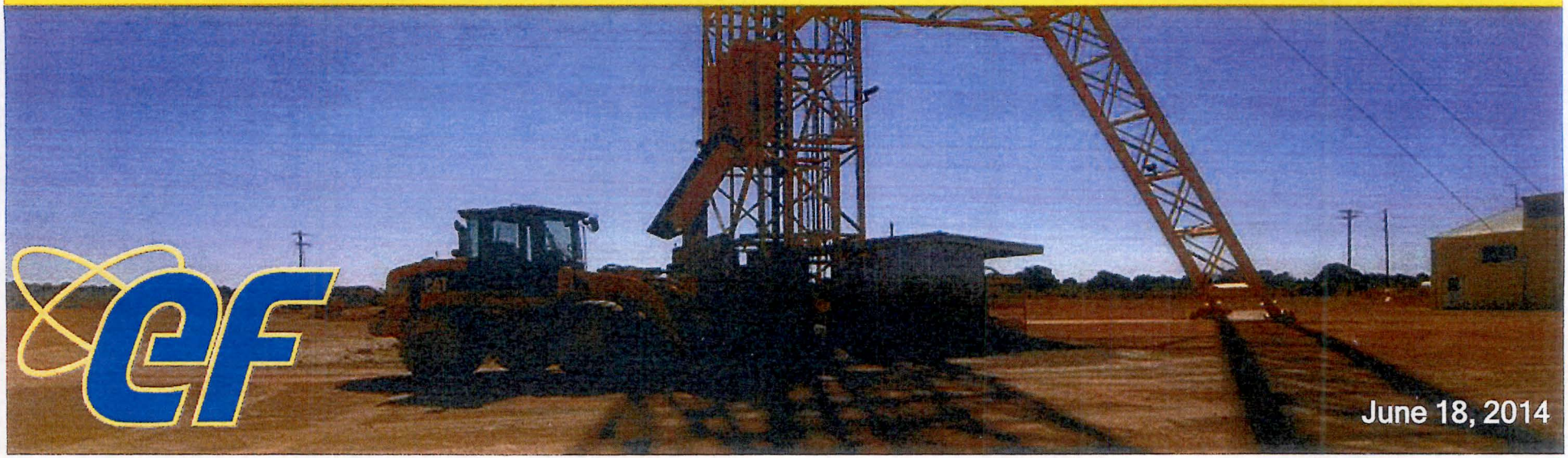
For more information contact our Customer Service department at 331.814.2200 or customerservice@landauerradon.com.

APPENDIX 4

ENERGY FUELS RESOURCES (USA) INC.

Radon Emissions Monitoring at Uranium Mines: Comparison of Alpha Track Detectors and Scintillation Cell Monitors

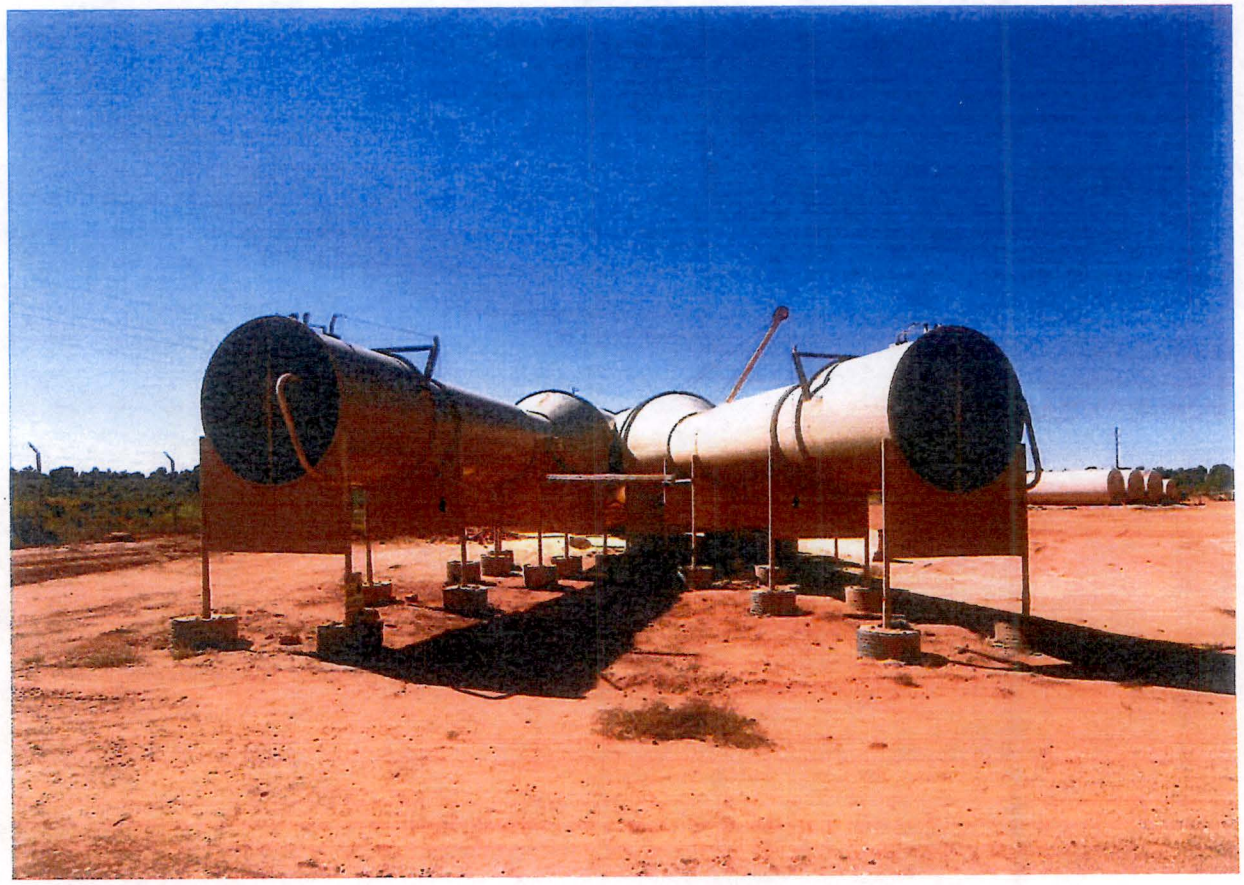
Presented to NMA NRC Uranium Recovery Workshop



June 18, 2014

Overview

1. Regulatory Framework
2. Study Objectives
3. Study Implementation
4. Challenges
5. Summary of Findings
6. Conclusions



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Regulatory Framework

National Emissions Standards for Hazardous Air Pollutants

EPA Regulation 40 CFR 61.07 Subpart B

61.22 "Emissions of radon-222 to the ambient air from an underground uranium mine shall not exceed those amounts that would cause any member of the public to receive in any year an effective does equivalent of 10 mrem/yr"

Test Method A-6:

1. Scintillation Cell Monitors
2. Specified in Appendix B Method 115
3. Does not need pre-approval from EPA

Test Method A-7:

1. Alpha track detector ("ATD")
2. Requires demonstration that ATD produces comparable data to scintillation cell monitor

Four Primary Study Objectives

1. Demonstrate that ATDs produce data comparable to data obtained with scintillation cell monitors;
2. Compare ATDs to scintillation cell monitors in different geographic settings;
3. Compare ATDs to scintillation cell monitors under a number of different physical conditions; and
4. Determine whether there is a statistically significant difference between the data collected from each monitoring device in order to develop a scintillation cell/ATD calibration factor.

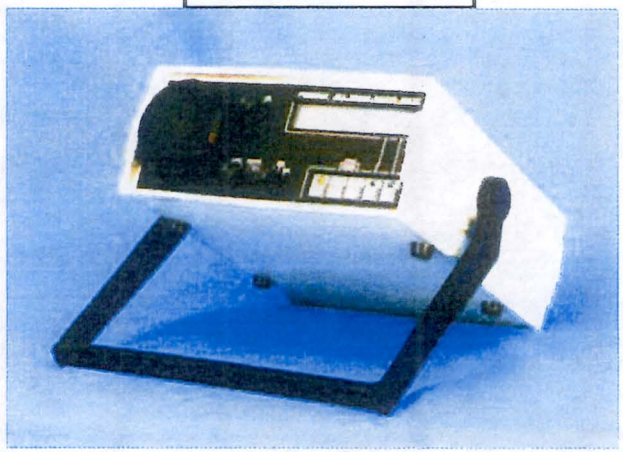
Two Secondary Study Objectives

1. Determine local background levels of radon near the La Sal Mines Complex using ATDs.
2. Determine the potential effect of thoron on the measurement of radon using ATDs and scintillation cell monitors.

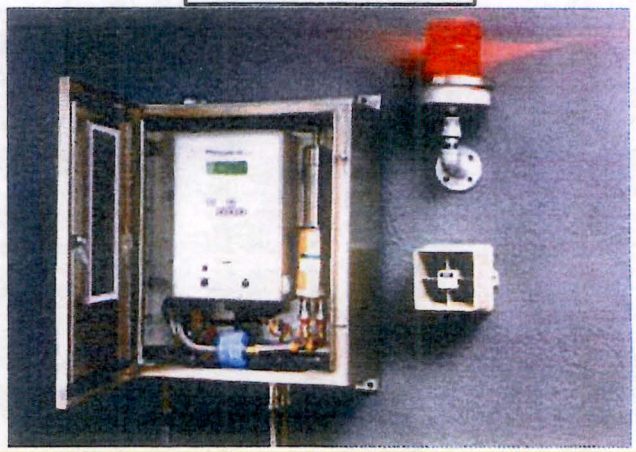
Study Implementation - Monitoring Devices Used

- **Method A-6 Scintillation Cell Monitors**
  1. **AB-5** – Records hourly data for 2 weeks
  2. **CRM-1** – Records hourly data for 1 month
- **Method A-7 Alpha Track Detector**
  1. **Radtrak Canister** – Measures average radon concentrations over the monitoring period.
     - Monitoring periods are typically 15-30 days

AB-5



CRM-1



Study Implementation - Locations

Mine	Vent Location	Monitoring Devices Used	Geographic Location	Environmental Conditions	Current, Typical Velocity and Flow Direction	Typical Radon Concentration
La Sal Mines Complex	Beaver 900	CRM-1, ATD	Colorado Plateau	extreme cold temperatures	Exhaust 24/7	**100-900 pCi/L**
	Snowball #2	CRM-1, ATD	Colorado Plateau	extreme cold temperatures	Exhaust 24/7 beginning of the test, intake 24/7 end of the test	**Non-detect - 4,000 pCi/L**
	Pandora 1	CRM-1, ATD	Colorado Plateau	extreme cold temperatures	Intake 24/7	**Non-detect - 200 pCi/L**
	Pandora Portal	AB-5, ATD	Colorado Plateau	extreme cold temperatures, high dust due to close proximity to haul road	No fan. Naturally upcast. Rate varies depending on mine conditions	**50-300 pCi/L**
	Beaver 1301	AB-5, ATD	Colorado Plateau	extreme cold temperatures, high moisture/humidity	Exhaust 24/7	**400-1,200 pCi/L**
	Beaver 2300 #2	AB-5, ATD	Colorado Plateau	extreme cold temperatures	Exhaust 24/7	**500-3,000 pCi/L**
Rim Mine	Rim Vent	AB-5, ATD	Colorado Plateau	extreme cold temperatures	Naturally upcast. Has a fan that runs approx. 12 hr/month for mine access	**100-4,000 pCi/L**
Pinenut Mine	Collar	AB-5, ATD	Arizona Desert	extreme heat and high dust	No fan. Naturally upcast. Rate varies depending on mine conditions	**Non-detect - 300 pCi/L**
	Pinenut Vent*	AB-5, ATD	Arizona Desert	extreme heat and high dust	Exhaust during operating hours in the beginning of the test, intake during operating hours end of the test	**Non-detect - 800 pCi/L**

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Study Implementation - Locations

Beaver Vent 2300 #2 at the La Sal Mines Complex

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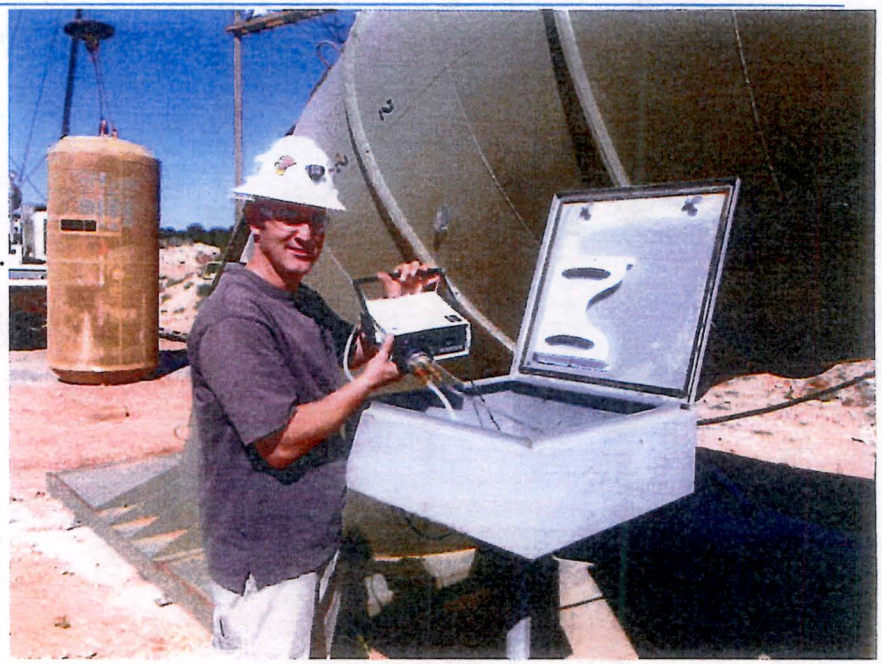
Study Implementation - Data Collection and Management

Field Data Collection/Download Schedule

- Method A-6 AB-5 – every two weeks
- Method A-6 CRM-1 – every 30 days
- Method A-7 ATDs for mine vent and portal monitoring – every 30 days,
- Method A-7 ATDs for radon background monitoring – every 90 days
- Method A-7 ATDs for presence of thoron monitoring – every 30 days (2 canisters each)

Data Management

- All data management, storage, evaluation, and calculation was conducted in EFRI's corporate office.
- ATDs were sent to Landauer for data processing.
- AB-5/CRM-1 was downloaded in the field.



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Challenges

- **Availability of Equipment**
  - Limited number of companies have equipment that can handle the high radon concentrations.
- **Maintenance of Equipment**
  - Each device requires 24/7 electricity
  - Each device and lucas cell must be sent for calibration annually.
  - Calibration can take 1-3 months.
  - All repairs have to be conducted off-site.
- **Equipment Failure and Downtime**
  - Monitoring devices are very sensitive to environmental conditions.
- **Data Management**
  - ATD data = 1 result/vent/month
  - AB-5 and CRM-1 data = 720 results/vent/month
  - AB-5 and CRM-1 data must be manipulated by hand to calculate average radon concentration.

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Summary of Findings

Objective #1 - Demonstrate that ATDs produce data comparable to data obtained with scintillation cell monitors

- Data results were consistent at radon concentrations between 0-200 pCi/L.
- ATD results were consistently higher at radon concentrations above 200 pCi/L.
- As monthly radon concentrations increased, the difference between the data reported from an ATD versus an AB-5 or CRM-1 also increased.
- ATDs reported 100% completeness.
- AB-5s reported 78% completeness.
- CRM-1s reported 51% completeness.

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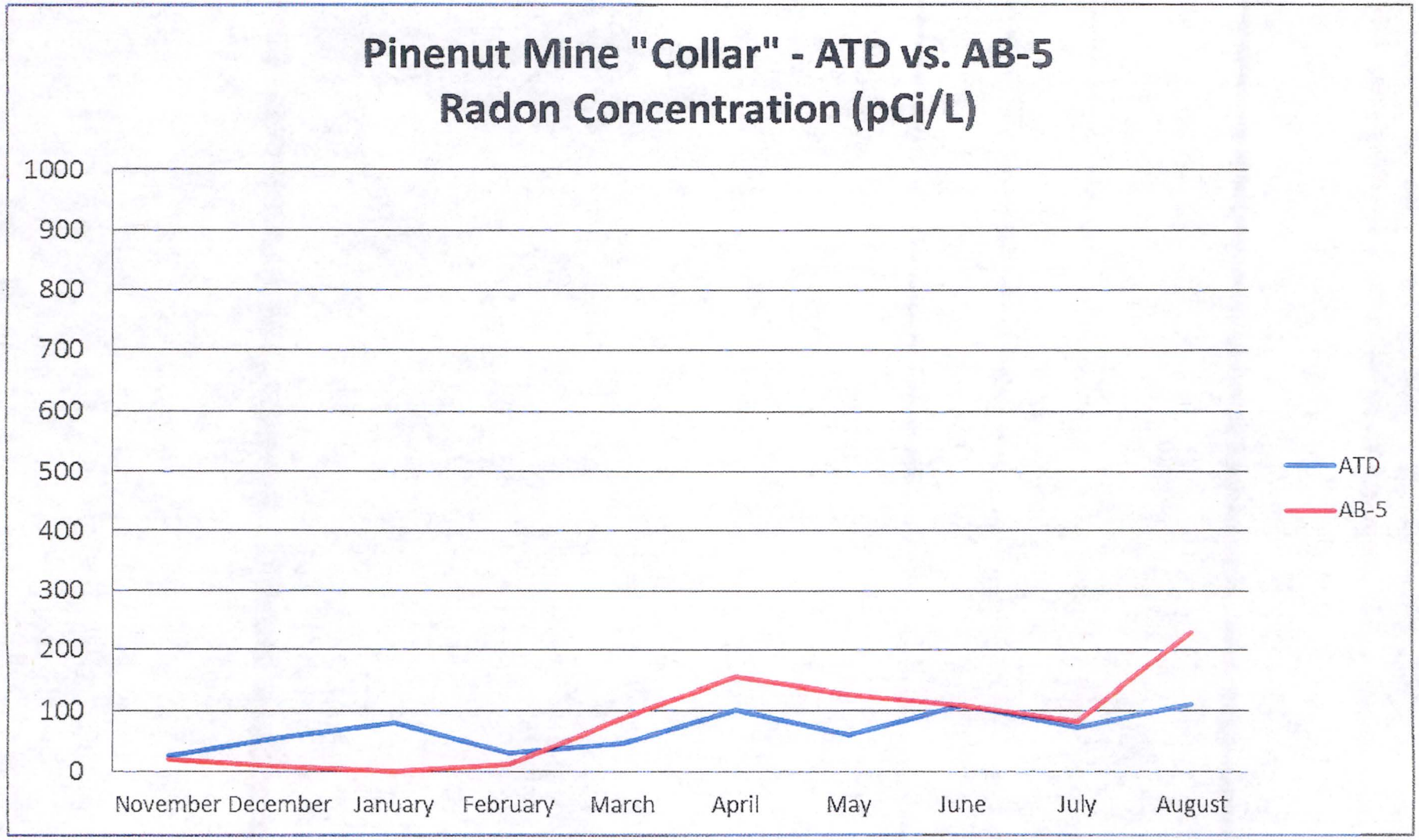
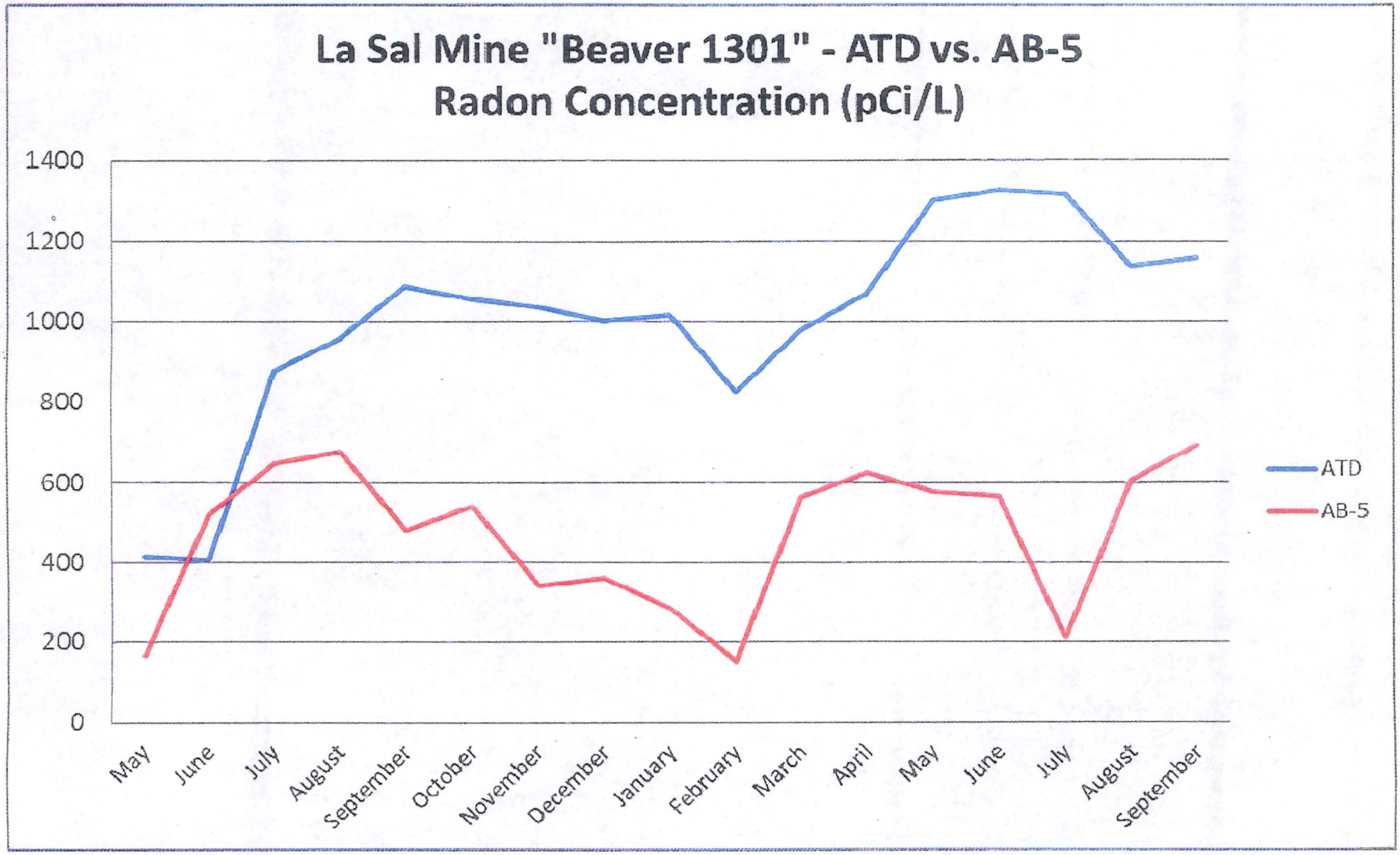
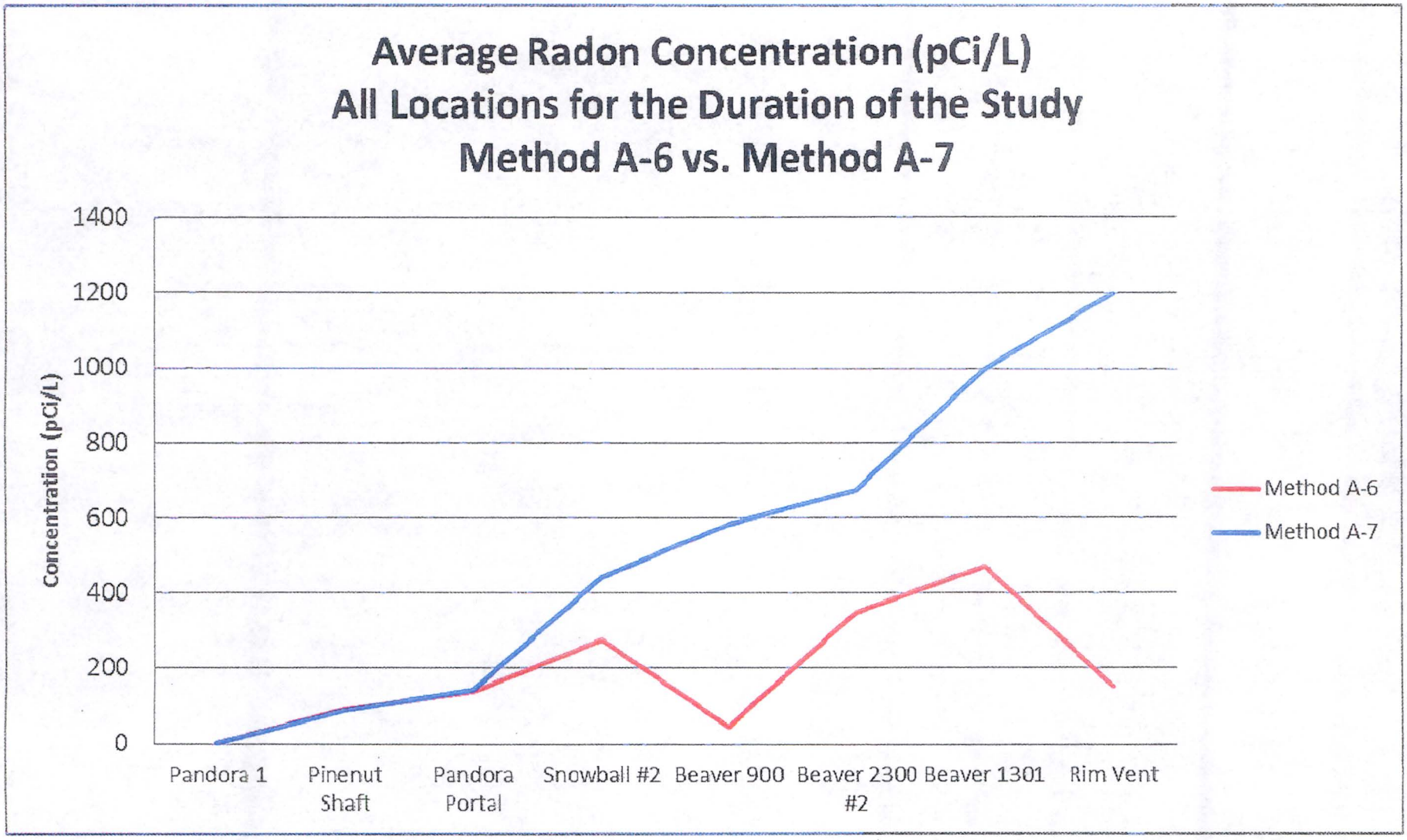
Summary of Findings



Summary of Findings



Summary of Findings



Summary of Findings

Objective #2 & #3 - Compare ATDs to Scintillation Cell Monitors in Different Geographic Settings and Physical Conditions

- 9 mine vents or portals at three mine sites in Utah and Arizona.
- 4 locations were intake vents or naturally ventilated access portals with radon concentrations less than 200 pCi/L.
- 5 locations were equipped with ventilation fans with radon concentrations above 200 pCi/L.
  - Velocities ranged from 1200-4000 fpm.
- Physical, environmental conditions did not impact ATD data collection.
  - Scintillation cell monitors sensitive to environmental conditions.
- In high velocity environments, the ATDs generally overestimate radon concentrations.

Summary of Findings

Objective #4 - Determine whether there is a statistically significant difference between the data collected from each monitoring device in order to develop an ATD calibration factor

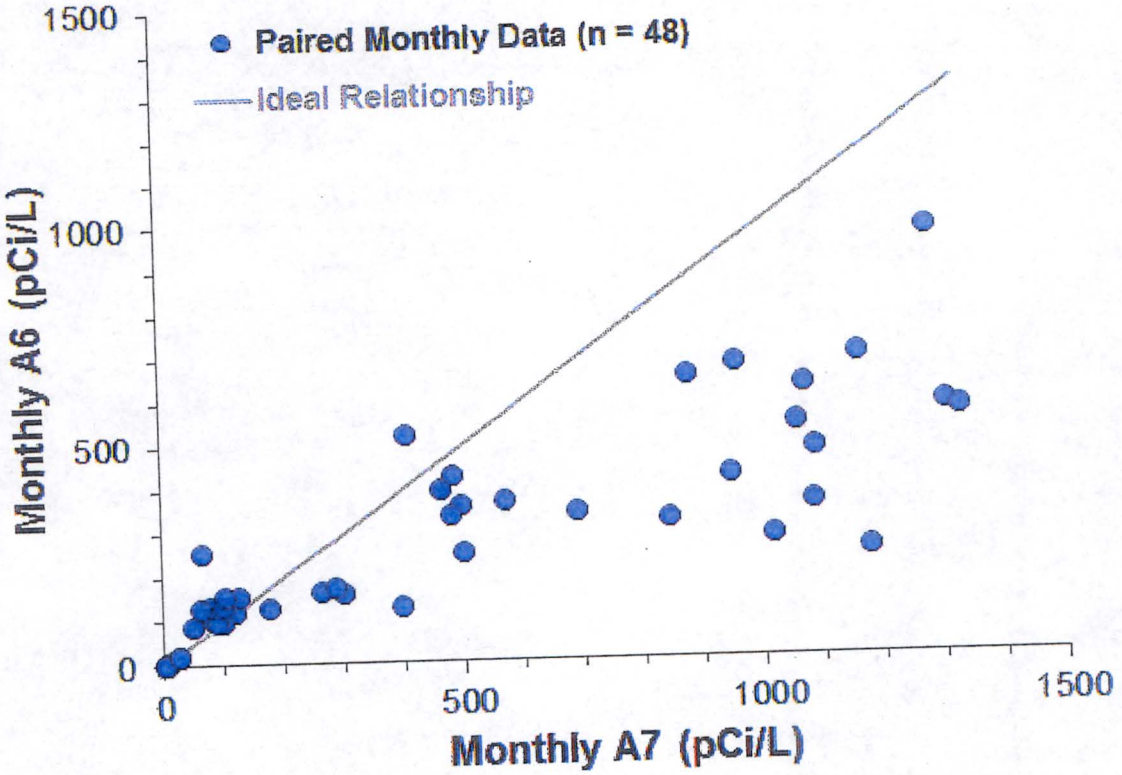
Statistical Analysis Framework:

1. A7 data calibration must not underestimate Method A6 measurements.
2. Only "complete" monthly data from each method used for validity of statistical comparisons (at least 90% data completeness).
3. Data of suspect quality due to monitoring problems (e.g. power interruptions, equipment malfunction) were excluded from statistical analysis.
4. Clear statistical outliers excluded from analysis (need representative data).

Summary of Findings

A6/A7 Relationship:

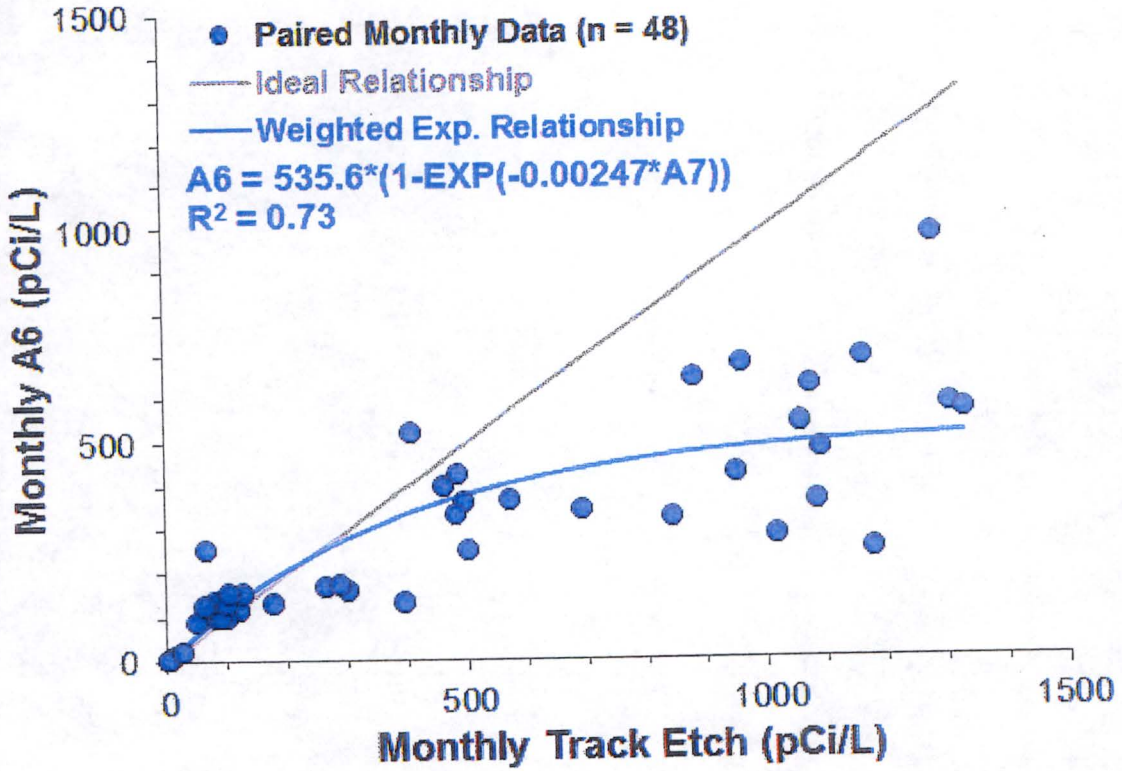
- Positive correlation, variance increases with increasing radon concentration.
- Method A7 values significantly overestimate A6 values above about 200 pCi/L



Summary of Findings

A6/A7 Relationship:

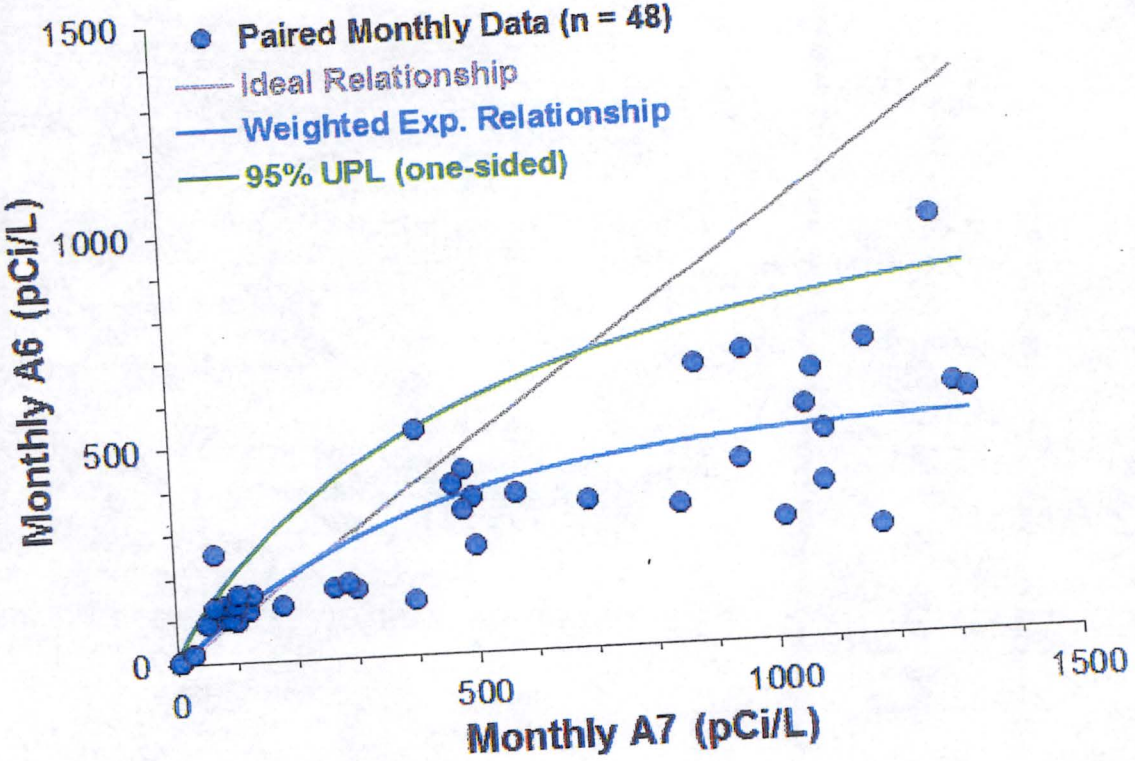
- Weighted non-linear function provides best statistical estimate of average relationship across observed range of values. Curve closely mimics ideal relationship below 200 pCi/L, but underestimation likely for higher values.



Summary of Findings

A6/A7 Relationship:

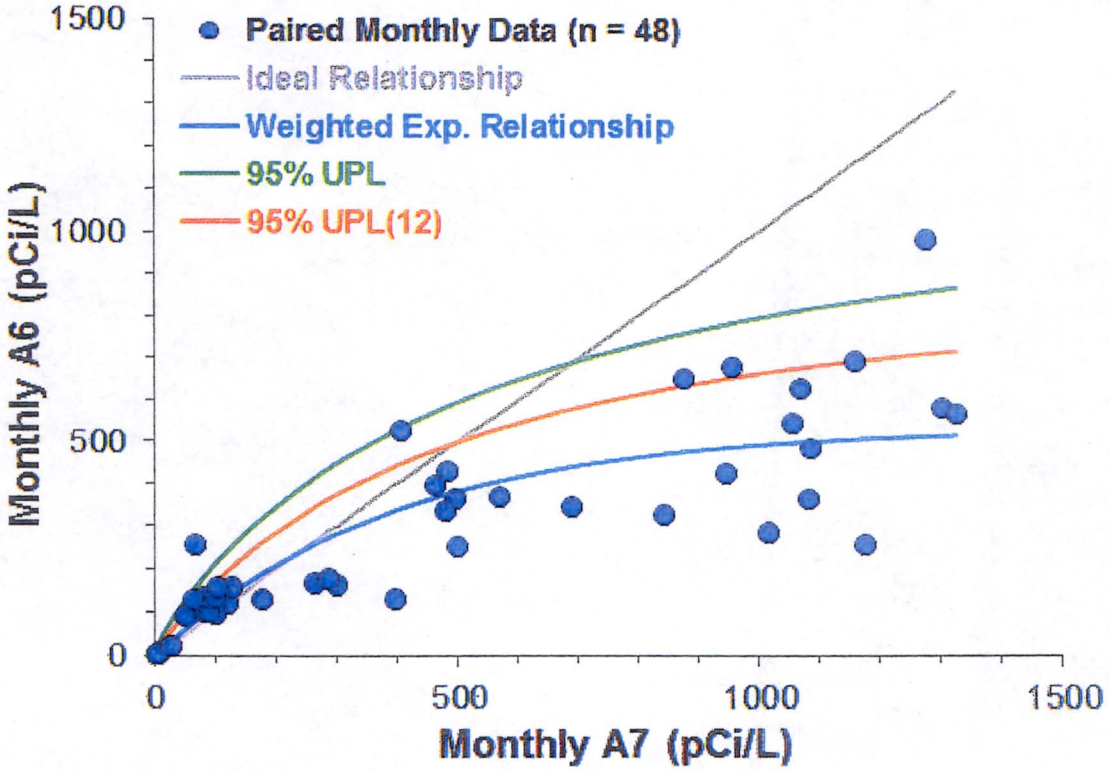
- One-sided 95% Upper Prediction Limit (UPL) limits underestimation of individual monthly A6 values to 5% probability or less.
- Dose to receptors modeled based on annual average, not individual monthly results.



Summary of Findings

A6/A7 Relationship:

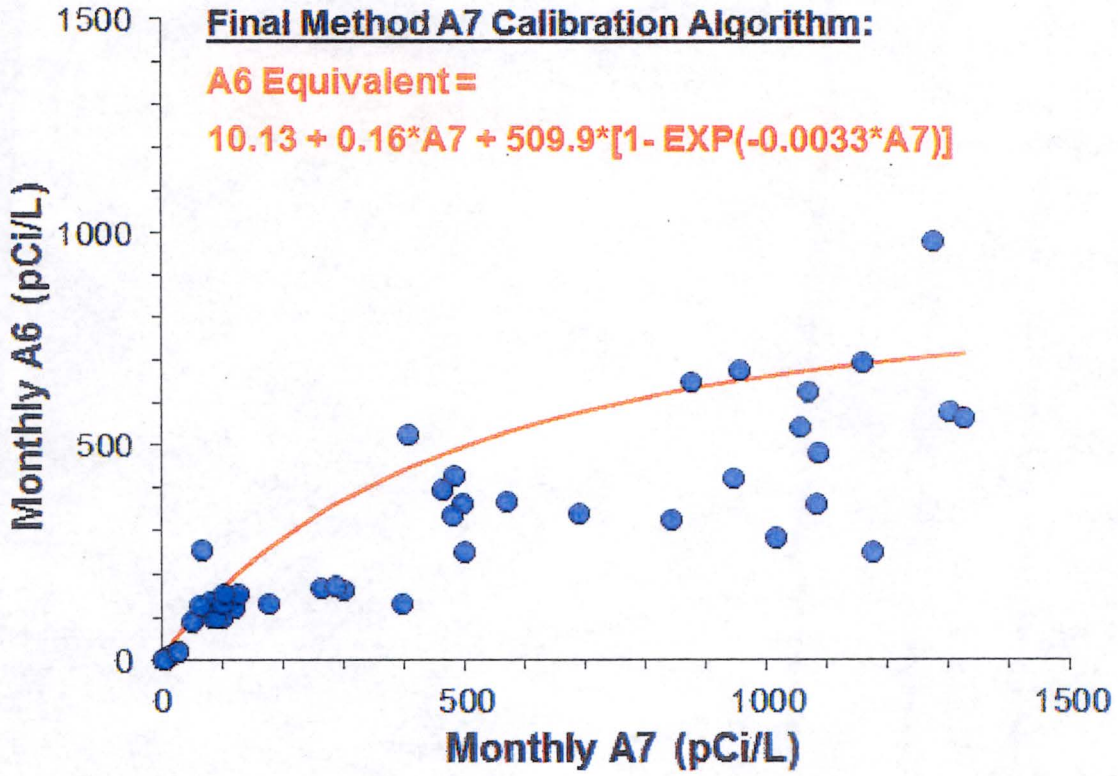
- An alternate 95% UPL based on reduced variance from average of 12 monthly measurements limits underestimation of annual A6 values to 5% probability or less.
- 95% UPL (12) curve provides a more accurate calibration with the appropriate degree of conservatism.



Summary of Findings

Final Method A7 Data Calibration Algorithm:

- Conservatively predicts A6-equivalent estimates based on Method A7 data.
- Limits probability of underestimating annual average A6 values to 5% or less.



Summary of Findings - Secondary Objectives

1. Radon Background Analysis

- Monitored in the 4 compass directions 0.5 and 2 miles from the mine site.
- Average concentration = approx. 0.4 pCi/L
- Concentration range = 0.06 (non-detect) to 1.2 pCi/L
- Comparable to past radon background study results in the region.

2. Potential Impact of Thoron

- Monitored by comparing ATDs with and without thoron shields.
- Monitored at 2 locations with 4 ATDs each.
- Non-thoron shielded ATDs not suited for high velocity mine conditions and extreme environments.
- Results indicated the difference in the data was due to environmental and physical conditions, not the presence of thoron.

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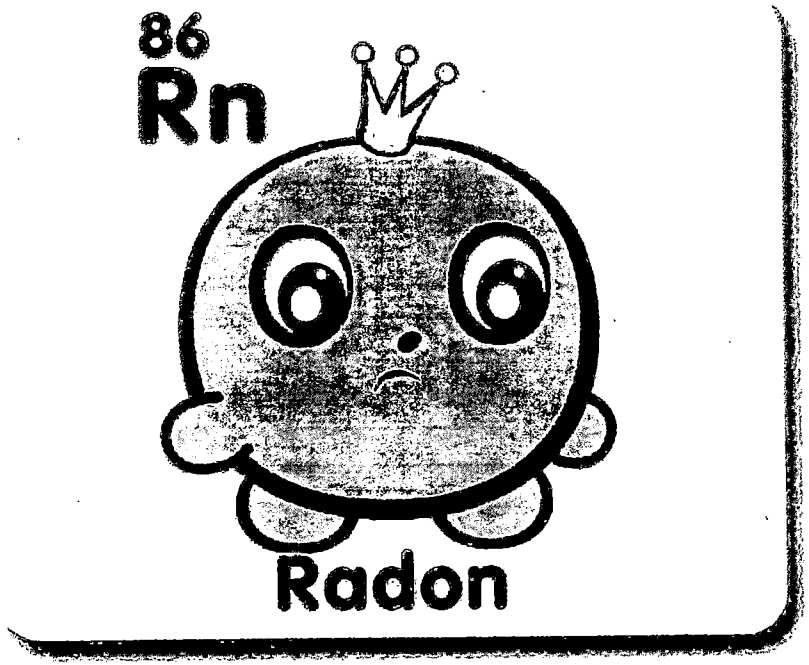
Conclusions

- Successfully achieved each of the data collection objectives.
- ATDs produce comparable, consistent, continuous, and reliable data.
- Scintillation cell monitors provide accurate and representative data, however, the devices proved to be unreliable and labor intensive in outdoor environments.
- ATDs produce data comparable to scintillation cell monitors at lower radon concentrations. (<200 pCi/L)
- ATDs overestimate radon concentrations in high velocity environments which result in higher radon concentrations (>200 pCi/L)
- Overall results were suitable for developing a calibration factor to account for overestimation when determining annual NESHAPs compliance.

Thank you



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