TETRA TECH

October 29, 2015

Mr. Tom Mahler
On-Scene Coordinator
U.S. Environmental Protection Agency, Region 7
11201 Renner Boulevard
Lenexa, Kansas 66219

Subject: Quality Assurance Project Plan for Radon Emanation Coefficient Study
West Lake Landfill Site, Bridgeton, Missouri
CERCLIS ID: MOD079900932
EPA Region 7, START 4, Contract No. EP-S7-13-06, Task Order No. 0007
Task Monitor: Tom Mahler and James Johnson, On-Scene Coordinators

Dear Mr. Mahler:

Tetra Tech, Inc. is submitting the attached Quality Assurance Project Plan regarding a study to evaluate radon emanation coefficient of core samples collected at the West Lake Landfill Site (WLLS) in Bridgeton, Missouri. If you have any questions or comments, please contact the Project Manager at (816) 412-1775.

Sincerely,

Robert Monnig, PE
START Project Manager

for Ted Faile, PG, CHMM
START Program Manager

Enclosures

cc: Debra Dorsey, START Project Officer (cover letter only)

X9025.14.0007.000

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QUALITY ASSURANCE PROJECT PLAN FOR RADON EMANATION COEFFICIENT STUDY

WEST LAKE LANDFILL SITE

Superfund Technical Assessment and Response Team (START) 4
Contract No. EP-S7-13-06, Task Order No. 0007

Prepared For:

U.S. Environmental Protection Agency
Region 7
Superfund Division
11201 Renner Blvd.
Lenexa, Kansas 66219

October 29, 2015

Prepared By:

Tetra Tech, Inc.
415 Oak Street
Kansas City, Missouri 64106
(816) 412-1741

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Region 7 Superfund Program Addendum to the Generic QAPP for Superfund Site Assessment and Targeted Brownfields Assessment Activities (October 2012) for the West Lake Landfill Site				
Project Information:				
Site Name: West Lake Landfill Site			**City:** Bridgeton	**State:** Missouri
EPA Project Manager: Tom Mahler and James Johnson			START Project Manager: Rob Monnig	
Approved By:	[signature]		**Prepared For:** EPA Region 7 Superfund Division	
Title:	START Project Manager	Date: 10/29/15		
Approved By:	[signature]			
Title:	for START Program Manager	Date: 10/29/15		
Approved By:	Kathy Homer		**Prepared By:** Rob Monnig **Date:** October 2015	
Title:	START QA Manager	Date: 10/29/2015		
Approved By:			Tetra Tech START Project Number: X9025.14.0007.000	
Title:	EPA Project Manager	Date:		
Approved By:				
Title:	EPA Region 7 QA Manager	Date:		

1.0 Project Management:

1.1 Distribution List:

EPA—Region 7: James Johnson, EPA On-Scene Coordinator
Tom Mahler, EPA On-Scene Coordinator
Bradley Vann, EPA Remedial Project Manager
Diane Harris, Region 7 QA Manager

START: Rob Monnig, Project Manager
Kathy Homer, QA Manager

1.2 Project/Task Organization:

Tom Mahler and James Johnson, of the EPA Region 7 Superfund Division, will serve as the EPA Project Manager for the activities described in this QAPP. Rob Monnig, of Tetra Tech, Inc., will serve as the START Project Manager.

1.3 Problem Definition/Background:

Description: This site-specific Quality Assurance Project Plan (QAPP) form is prepared as an addendum to the Generic QAPP for Superfund Site Assessment and Targeted Brownfields Assessment Programs (updated October 2012), and contains site-specific data quality objectives for the sampling activities described herein.

☒ Description attached.

☐ Description in referenced report: ____________________ (Title) ____________ (Date)

1.4 Project/Task Description:

☐ CERCLA PA ☐ CERCLA SI ☐ Brownfields Assessment
☐ Other (description attached): ☐ Pre-CERCLIS Site Screening ☒ Removal Assessment

Schedule: Receipt of core samples from the potentially responsible party (PRP) is anticipated in November or December 2015. Upon receipt of samples, EPA and START will ship samples to the analytical laboratory. Analysis of the samples for determination of radon emanation coefficient is anticipated to require 60 days.

☐ Description in referenced report: ____________________ (Title) ____________ (Date)

1.5 Quality Objectives and Criteria for Measurement Data:

Accuracy:	☒ Identified in attached table.
Precision:	☒ Identified in attached table.
Representativeness:	☒ Identified in attached table.
Completeness*:	☒ Identified in attached table.
Comparability:	☒ Identified in attached table.

Other Description:

*A completeness goal of 100 percent has been established for this project. However, if the completeness goal is not met, EPA may still be able to make site decisions based on any or all of the remaining validated data.

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1.6 Special Training/Certification Requirements:

☒ OSHA 1910
☐ Special Equipment/Instrument Operator:
☐ Other (describe below):

1.7 Documentation and Records:

☒ Field Sheets ☒ Site Log ☐ Trip Report ☒ Site Maps ☐ Video
☒ Chain of Custody ☒ Health and Safety Plan ☒ Letter Report ☒ Photos

☒ Sample documentation will follow EPA Region 7 SOP 2420.05.

☒ Other: Analytical information will be handled according to procedures identified in Table 2.

2.0 Measurement and Data Acquisition:

2.1 Sampling Process Design:

☐ Random Sampling ☐ Transect Sampling ☒ Biased/Judgmental Sampling ☐ Stratified Random Sampling
☐ Search Sampling ☐ Systematic Grid ☐ Systematic Random Sampling ☒ Definitive Sampling
☐ Screening w/o Definitive Confirmation ☐ Screening w/ Definitive Confirmation
☐ Sample Map Attached

The purpose of the study is to evaluate the radon emanation coefficient of radiologically impacted material (RIM) at the Westlake landfill. Therefore, core samples that exhibit elevated gamma activity, indicating presence of RIM, will be selected for laboratory analysis. As part of the procedure for determining the radon emanation coefficient of the samples, the analytical laboratory will also definitively determine radium-226, isotopic uranium, and isotopic thorium activities of samples. See Appendix A for additional site-specific information.

Sample Summary Location	Matrix	# of Samples*	Analysis
Core samples from Operable Unit 1 (OU1) of Westlake Landfill exhibiting elevated gamma activity indicating presence of RIM	Solid	6	Radon emanation coefficient, moisture content, radium-226, isotopic uranium and thorium

2.2 Sample Methods Requirements:

Matrix	Sampling Method	EPA SOP(s)/Methods
Solid landfill material	EPA/START will receive core samples collected by the PRP	Samples will be collected by the PRP in accordance with their approved workplan[1] (see http://www3.epa.gov/region07/cleanup/west_lake_landfill/pdf/west-lake-revised-work-plan-9-22-15.pdf)

2.3 Sample Handling and Custody Requirements:

☐ Samples will be packaged and preserved in accordance with procedures defined in Region 7 EPA SOP 2420.06.
☒ COC will be maintained as directed by Region 7 EPA SOP 2420.04.
☐ Samples will be accepted according to Region 7 EPA SOP 2420.01.

☒ Other (Describe): Samples will be packaged and accepted according to procedures established by the START-contracted laboratory.

2.4 Analytical Methods Requirements:

☒ Identified in attached table.
☒ Rationale: The requested analyses have been selected to provide an assessment of the radon emanation coefficient exhibited by RIM material.
☐ Other (Describe):

2.5 Quality Control Requirements:

☐ Not Applicable
☐ Identified in attached table.
☐ In accordance with the Generic QAPP for Superfund Site Assessment and Targeted Brownfields Assessment Programs (updated October 2012).
☒ Describe Field QC Samples: No field QC samples will be required.

☐ Other (Describe):

2.6 Instrument/Equipment Testing, Inspection, and Maintenance Requirements:

☐ Not Applicable
☒ In accordance with the Generic QAPP for Superfund Site Assessment and Targeted Brownfields Assessment Programs (updated October 2012).
☐ Other (Describe):

2.7 Instrument Calibration and Frequency:

☐ Not Applicable
☒ Inspection/acceptance requirements accord with the Generic QAPP for Superfund Site Assessment and Targeted Brownfields Assessment Programs (updated October 2012).
☒ Calibration of laboratory equipment will be performed as described in the SOPs and/or manufacturers' recommendations referenced in Table 1.
☐ Other (Describe):

2.8 Inspection/Acceptance Requirements for Supplies and Consumables:

☐ Not Applicable
☒ In accordance with the Generic QAPP for Superfund Site Assessment and Targeted Brownfields Assessment Programs (updated October 2012).
☐ All sample containers will meet EPA criteria for cleaning procedures for low-level chemical analysis. Sample containers will have Level II certifications provided by the manufacturer in accordance with pre-cleaning criteria established by EPA in *Specifications and Guidelines for Obtaining Contaminant-Free Containers.*
☒ Other (Describe): Samples will be packaged in food-grade plastic containers or sealable bags.

2.9 Data Acquisition Requirements:

☐ Not Applicable
☒ In accordance with the Generic QAPP for Superfund Site Assessment and Targeted Brownfields Assessment Programs (updated October 2012).
☐ Previous data/information pertaining to the site (including other analytical data, reports, photos, maps, etc., which are referenced in this QAPP) have been compiled by EPA and/or its contractor(s) from other sources. Some of that data has not been verified by EPA and/or its contractor(s); however, the information will not be used for decision-making purposes by EPA without verification by an independent professional qualified to verify such data/information.
☐ Other (Describe):

2.10 Data Management:

☐ All laboratory data acquired will be managed in accordance with Region 7 EPA SOP 2410.01.
☒ Other (Describe): All laboratory data acquired will be managed according to procedures established by the START-contracted laboratory.

3.0 Assessment and Oversight:

3.1 Assessment and Response Actions:

☒ Peer Review ☒ Management Review ☐ Field Audit ☐ Lab Audit

☐ Assessment and response actions pertaining to analytical phases of the project are addressed in Region 7 EPA SOPs 2430.06 and 2430.12.

☐ Other (Describe):

3.1A Corrective Action:

☒ Corrective actions will be taken at the discretion of the EPA Project Manager whenever there appear to be problems that could adversely affect data quality and/or resulting decisions affecting future response actions pertaining to the site.

☐ Other (Describe):

3.2 Reports to Management:

☐ Audit Report ☒ Data Validation Report ☐ Project Status Report ☐ None Required

☒ A letter report describing the sampling techniques, locations, problems encountered (with resolutions to those problems), and interpretation of analytical results will be prepared by Tetra Tech START and submitted to the EPA.
☒ Reports will be prepared in accordance with the Generic QAPP for Superfund Site Assessment and Targeted Brownfields Assessment Programs (updated October 2012).
☐ Other (Describe):

Region 7 Superfund Program Addendum to the Generic QAPP for Superfund Site Assessment and Targeted Brownfields Assessment Activities (October 2012) for the West Lake Landfill Site
4.0 Data Validation and Usability:

4.1 Data Review, Validation, and Verification Requirements:

- ☐ Identified in attached table:
- ☒ Data review and verification will accord with the Generic QAPP for Superfund Site Assessment and Targeted Brownfields Assessment Programs (updated October 2012).
- ☐ Data review and verification will be performed by a qualified analyst and the laboratory's section manager as described in Region 7 EPA SOPs 2430.06, 2410.10, and 2430.12.
- ☒ Other (Describe): The analytical data package from the START-contracted laboratory will be validated internally by the contracted laboratory in accordance with the laboratory's established SOPs. A START chemist will conduct an external verification and validation of the laboratory data package.

4.2 Validation and Verification Methods:

- ☐ Identified in attached table:
- ☐ The data will be validated in accordance with Region 7 EPA SOPs 2430.06, 2410.10, and 2430.12.
- ☒ Other (Describe): The data will be validated using methods consistent with a Stage 2B validation, as described in the EPA Contract Laboratory Program (CLP) *Guidance for Labeling Externally Validated Laboratory Analytical Data for Superfund Use* (EPA 2009). A Stage 2B validation includes verification and validation based on a completeness and compliance check of sample receipt conditions and sample-related and instrument-related QC results. The EPA Project Manager will be responsible for overall validation and final approval of the data, in accordance with the projected use of the results.

4.3 Reconciliation with User Requirements:

- ☐ Identified in attached table:
- ☒ If data quality indicators do not meet the project's requirements as outlined in this QAPP, the data may be discarded and re-sampling or re-analysis of the subject samples may be required by the EPA Project Manager.
- ☐ Other (Describe):

<table>
<tr><th colspan="7">Region 7 Superfund Program
Addendum to the Generic QAPP for Superfund Site Assessment and Targeted Brownfields Assessment Activities (October 2012) for the West Lake Landfill Site</th></tr>
<tr><th colspan="7">Table 1: Sample Summary</th></tr>
<tr><td colspan="4">Site Name: West Lake Landfill Site</td><td colspan="3">Location: Bridgeton, Missouri</td></tr>
<tr><td colspan="4">START Project Manager: Rob Monnig</td><td>Activity/ASR #: NA</td><td colspan="2">Date: October 2015</td></tr>
<tr><td>No. of Samples</td><td>Matrix</td><td>Location</td><td>Purpose</td><td>Requested Analysis</td><td>Sampling Method</td><td>Analytical Method/SOP</td></tr>
<tr><td rowspan="5">6</td><td rowspan="5">Solid landfill material</td><td rowspan="5">Areas 1 and 2 of Operable Unit-1 at the West Lake Landfill</td><td rowspan="5">Assess radon emanation coefficient of sample at various moisture contents and before and after thermal treatment</td><td>Radon emanation coefficient</td><td rowspan="5">Samples will be collected by the PRP in accordance with their approved workplan[1]</td><td>Southwest Research Institute procedure[2]</td></tr>
<tr><td>Gamma spec., including Ra-226</td><td>Gamma spec. per lab SOP[2] preceded by 21-day in-growth of Ra-226 progeny</td></tr>
<tr><td>Isotopic U (U-234, -235, -238)</td><td>ICP-MS isotopic uranium per lab SOP[2]</td></tr>
<tr><td>Isotopic Th (Th-228, -230, -232)</td><td>Alpha spec. per lab SOP[2]</td></tr>
<tr><td>Moisture content</td><td>Per lab SOP[2]</td></tr>
</table>

Notes:

[1] See http://www3.epa.gov/region07/cleanup/west_lake_landfill/pdf/west-lake-revised-work-plan-9-22-15.pdf

[2] See Appendix C

Alpha spec.	Alpha spectroscopy
EPA	U.S. Environmental Protection Agency
gamma spec.	Gamma spectroscopy
ICP-MS	Inductively coupled plasma mass spectrometry
NA	Not applicable
lab	Laboratory
Ra	Radium
SOP	Standard Operating Procedure
Th	Thorium
U	Uranium

Region 7 Superfund Program Addendum to the Generic QAPP for Superfund Site Assessment and Targeted Brownfields Assessment Activities (October 2012) for the West Lake Landfill Site								
Table 2: Data Quality Objective Summary								
Site Name: West Lake Landfill Site				**Location:** Bridgeton, Missouri				
START Project Manager: Rob Monnig				**Activity/ASR #:** N/A (START-contracted laboratory)			**Date:** October 2015	
Analysis	Analytical Method	Data Quality Measurements					Sample Handling Procedures	Data Management Procedures
		Accuracy	Precision	Representativeness	Completeness	Comparability		
Radon emanation coefficient	See Table 1	Per analytical method	Per analytical method	Core samples exhibiting elevated gamma activity, indicating presence of RIM, will be selected.	The completeness goal is 100%; however, no individual samples have been identified as critical samples.	The laboratory has developed a procedure comparable to procedures used in previous studies of radon emanation (see Strong and Levins 1982).	See Section 2.3 of QAPP form.	See Section 2.10 of QAPP form.
Gamma spec., including Ra-226	See Table 1	Per analytical method	Per analytical method	Core samples exhibiting elevated gamma activity, indicating presence of RIM, will be selected.	The completeness goal is 100%; however, no individual samples have been identified as critical samples.	Standardized procedures will be used.	See Section 2.3 of QAPP form.	See Section 2.10 of QAPP form.
Isotopic U (U-234, -235, -238)	See Table 1	Per analytical method	Per analytical method	Core samples exhibiting elevated gamma activity, indicating presence of RIM, will be selected.	The completeness goal is 100%; however, no individual samples have been identified as critical samples.	Standardized procedures will be used.	See Section 2.3 of QAPP form.	See Section 2.10 of QAPP form.
Isotopic Th (Th-228, -230, -232	See Table 1	Per analytical method	Per analytical method	Core samples exhibiting elevated gamma activity, indicating presence of RIM, will be selected.	The completeness goal is 100%; however, no individual samples have been identified as critical samples.	Standardized procedures will be used.	See Section 2.3 of QAPP form.	See Section 2.10 of QAPP form.
Moisture content	See Table 1	Per analytical method	Per analytical method	Core samples exhibiting elevated gamma activity, indicating presence of RIM, will be selected.	The completeness goal is 100%; however, no individual samples have been identified as critical samples.	Standardized procedures will be used.	See Section 2.3 of QAPP form.	See Section 2.10 of QAPP form.

APPENDIX A

SITE-SPECIFIC INFORMATION REGARDING RADON EMANATION COEFFICIENT STUDY

INTRODUCTION

The Tetra Tech, Inc. (Tetra Tech) Superfund Technical Assessment and Response Team (START) has been tasked by the U.S. Environmental Protection Agency (EPA) to assist with a study to evaluate the radon emanation characteristics of core samples collected at the West Lake Landfill site (WLSS) in Bridgeton, Missouri. Rob Monnig of Tetra Tech will serve as the START Project Manager. He will be responsible for ensuring that the study proceeds as described in this Quality Assurance Project Plan (QAPP), and for providing periodic updates to the client concerning the status of the project, as needed. Bradley Vann and Tom Mahler will be the EPA Project Managers for this activity.

START's tasks will include, but will not be limited to: (1) engaging an analytical laboratory capable of preparing and implementing an analytical procedure to determine the radon emanation coefficient of core samples, (2) assisting with reception of core samples from the potentially responsible party (PRP) and coordinating shipment of samples to the laboratory, (3) assisting EPA with data acquisition and management, and (4) documenting the study efforts. The Tetra Tech START Quality Assurance (QA) Manager will provide technical assistance, as needed, to ensure that necessary QA issues are adequately addressed.

START will adhere to this QAPP as much as possible, but may alter proposed activities in the field if warranted by site-specific conditions and unforeseen hindrances that prevent implementation of any aspect of this QAPP in a feasible manner. Such deviations will be recorded in the site logbook, as necessary. This QAPP will be available to the field team at all times during sampling activities to serve as a key reference for the proposed activities described herein.

PROBLEM DEFINITION, BACKGROUND, AND SITE DESCRIPTION

West Lake Landfill is an approximately 200-acre property that includes several closed solid waste landfill units that accepted wastes for landfilling from the 1940s or 1950s through 2004, plus a solid waste transfer station, a concrete plant, and an asphalt batch plant. The WLLS is at 13570 St. Charles Rock Road in Bridgeton, St. Louis County, Missouri, approximately 1 mile north of the intersection of Interstate 70 and Interstate 270 (see Appendix B, Figure 1). The WLLS was used for limestone quarrying and crushing operations from 1939 through 1988. Beginning in the late 1940s or early 1950s, portions of the quarried areas and adjacent areas were used for landfilling municipal refuse, industrial solid wastes, and construction/demolition debris. In 1973, approximately 8,700 tons of leached barium sulfate residues (a remnant from the Manhattan Engineer District/Atomic Energy Commission project) were reportedly mixed with approximately 39,000 tons of soil from the 9200 Latty Avenue site in Hazelwood, Missouri, transported to the WLLS, and used as daily or intermediate cover material. In December 2004, the Bridgeton Sanitary Landfill—the last landfill unit to receive solid waste—stopped receiving waste pursuant to an agreement with the City of St. Louis to reduce potential for birds to interfere with Lambert Field International Airport operations. In December 2010, Bridgeton Landfill detected changes—elevated temperatures and elevated carbon monoxide levels—in its landfill gas extraction system in use at the South Quarry of the Bridgeton Sanitary Landfill portion of the site (a landfill portion not associated with known radiologically impacted material [RIM]). Further investigation indicated that the South Quarry Pit landfill was undergoing an exothermic subsurface smoldering event (SSE). EPA is conducting this radon emanation study to inform investigators about potential effects of an SSE on radon emanation rates.

SAMPLING PROCESS DESIGN AND RATIONALE

Design of and rationale for the sampling process for this study are developed via the 7-step process of establishing data quality objectives (DQO). This process is described in the EPA documents *Data Quality Objectives Process for Hazardous Waste Site Investigations* (EPA QA/G-4HW, January 2000, EPA/600/R-00/007) and *Guidance for the Data Quality Objectives Process* (EPA QA/G-4, February 2006, EPA/240/B-06/001).

Step 1 – State the Problem

Problem Statement

An SSE in one of the non-radiological disposal cells has been reported. Some have hypothesized that an SSE could increase the rate of radon release from the subsurface. A measurable parameter of particular interest for modeling radon release is the radon emanation coefficient. Although literature values from previous studies of radon emanation coefficients of various materials (mostly uranium tailings and soils) are available, it may be desirable to obtain site-specific radon emanation coefficients determined experimentally via a bench-scale study using West Lake RIM. Moreover, the bench-scale study could test if the actions of an SSE could cause physical or chemical changes to the RIM that alter the material's radon emanation coefficient.

Conceptual Site Model of Environmental Hazard to be Evaluated

An SSE event could cause a change in subsurface moisture and/or the physical/chemical makeup of the RIM, which may affect the radon emanation coefficient. The radon emanation coefficient quantifies the fraction of radon that escapes from solid material into the adjacent pore space (see Strong and Levins 1982). Experimentally determined radon emanation coefficients yielded from a study of RIM-containing material subjected to various moisture content and thermal treatment may inform investigators regarding effects of an SSE on radon emanation rates.

Alternative Approaches

In the absence of experimentally determined radon emanation coefficients, investigators could evaluate sensitivity of modeled radon release rates to a range of radon emanation coefficients and other parameters related to subsurface conditions (such as moisture content). A review of published literature could inform investigators regarding the probable range of the radon emanation coefficient.

Step 2 – Identify the Decision

Principal Study Question

Experimental data will be used to answer these principal study questions:

- **Question 1**: What is the radon emanation coefficient of RIM-containing samples at various moisture contents?
- **Question 2:** Does thermal treatment of a RIM-containing sample alter the sample's radon emanation coefficient?

Decision Statement / Alternative Actions

No decision statement or alternative actions are associated with this study. The study will inform data users regarding radon emanation characteristics of RIM-containing samples subjected to moisture and thermal treatment.

Step 3 – Identify Inputs to the Decision

The principal study questions will be answered by experimentally determining the radon emanation coefficient of RIM-containing samples collected at OU1 of the West Lake Landfill. Measuring the radon emanation coefficient involves placing radium-226-impacted material within an air-tight chamber, allowing accumulation of radon gas within the sealed chamber for a period of time, and then determining radon concentration in the chamber air and radium-226 concentration in the impacted material. A laboratory has been engaged to perform this study and has developed a procedure (see Appendix C).

Step 4 – Define the Boundaries of the Study

Target Population

The target population is the West Lake Landfill RIM from Areas 1 or 2 of Operable Unit 1 (OU1) (see Appendix B, Figure 1). Samples from Area 1 or 2 of OU1 that exhibit significantly elevated gamma activity will presumably contain RIM, and selected samples will be submitted for laboratory determination of radon emanation coefficients. Submitted samples will also undergo laboratory analysis for uranium/thorium isotopes and radium-226; data then can be used to evaluate if the sample is representative of radionuclide concentrations historically detected in RIM-containing samples.

Spatial and Temporal Boundaries

Samples will be collected from Area 1 or 2 of OU1 of the West Lake Landfill, and will be selected to represent RIM-containing material. Temporal boundaries are not a significant aspect of this study; the half-life of radium-226, the parent radionuclide of radon-222, is about 1,600 years.

Practical Constraints on Acquiring the Data

No practical constraints have been identified.

Define the Scale of Inference

Radon emanation coefficients determined for various moisture content and thermal-treatment would be representative of the site and could be used in future radon modeling efforts. The study would not provide information to infer changes in radon flux related to landfill settling, development of fissures in cover due to drying, or any advective transport of radon.

Steps 5 and 6 – Develop a Decision Rule and Specify Tolerable Limits on Decision Errors

The study will provide data regarding the radon emanation coefficient of RIM-containing material at various levels of moisture content, and under pre- and post-thermal treatment conditions. Alternative actions related to this study have not been identified; therefore, a decision rule and specification of tolerable limits on decision errors are not needed.

Step 7 – Optimize the Design for Obtaining Data

Previous studies have characterized radon emanation coefficients of soils, uranium ores, and uranium tailings. The Argonne National Laboratory (ANL) summarized several studies in *Data Collection Handbook to Support Modeling Impacts of Radioactive Material in Soil*; in these studies, the radon emanation coefficient was found to vary from 0.02 to 0.70 in soils (ANL 1993).

Data from previous studies also demonstrate a strong influence of moisture content on radon emanation coefficients. This exhibit from the Strong and Levins (1982) study of uranium mill tailings illustrates the influence of moisture content determined in their study:

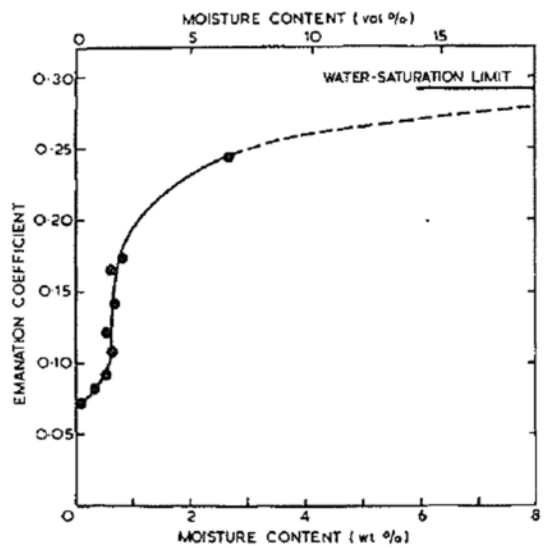


FIG. 2. Variation of emanation coefficient with moisture content for Jabiluka tailings.

Effects of heating on emanation coefficients have also been studied. Garver and Baskaran (2004) found that minerals in their study that had been heated to 600 degrees Celsius (ºC) exhibited lower radon emanation coefficients than studied minerals that had not been heated. The researchers hypothesized that heating anneals nuclear tracks (created from previous decay events) within the mineral that serve as conduits for release of radon.

The samples for this study will be subjected to a combination of moisture and thermal treatments; a radon emanation coefficient will be determined for each treatment of the sample. The analytical laboratory has proposed nine different moisture and thermal treatments; these are described in Section E of the laboratory procedure (see Appendix C). The thermal treatments include subjecting samples to temperatures of 105 ºC and 250 ºC for 16 or 48 hours. The 105 ºC treatment temperature was selected to simulate loss of liquid water from the sample at temperatures near the boiling point of water. The 250 ºC temperature was selected to induce smoldering of the sample and to approximate the upper-end of the expected temperature yielded by an SSE in the landfill. Two durations of thermal treatment—16 and 48 hours—were selected to assess for possible variation in the radon emanation coefficient due to varying degrees of drying/smoldering of the samples.

Analyses of six core samples is anticipated, each to undergo the nine aforementioned treatments, resulting in measurement of 54 radon emanation coefficients.

REFERENCES

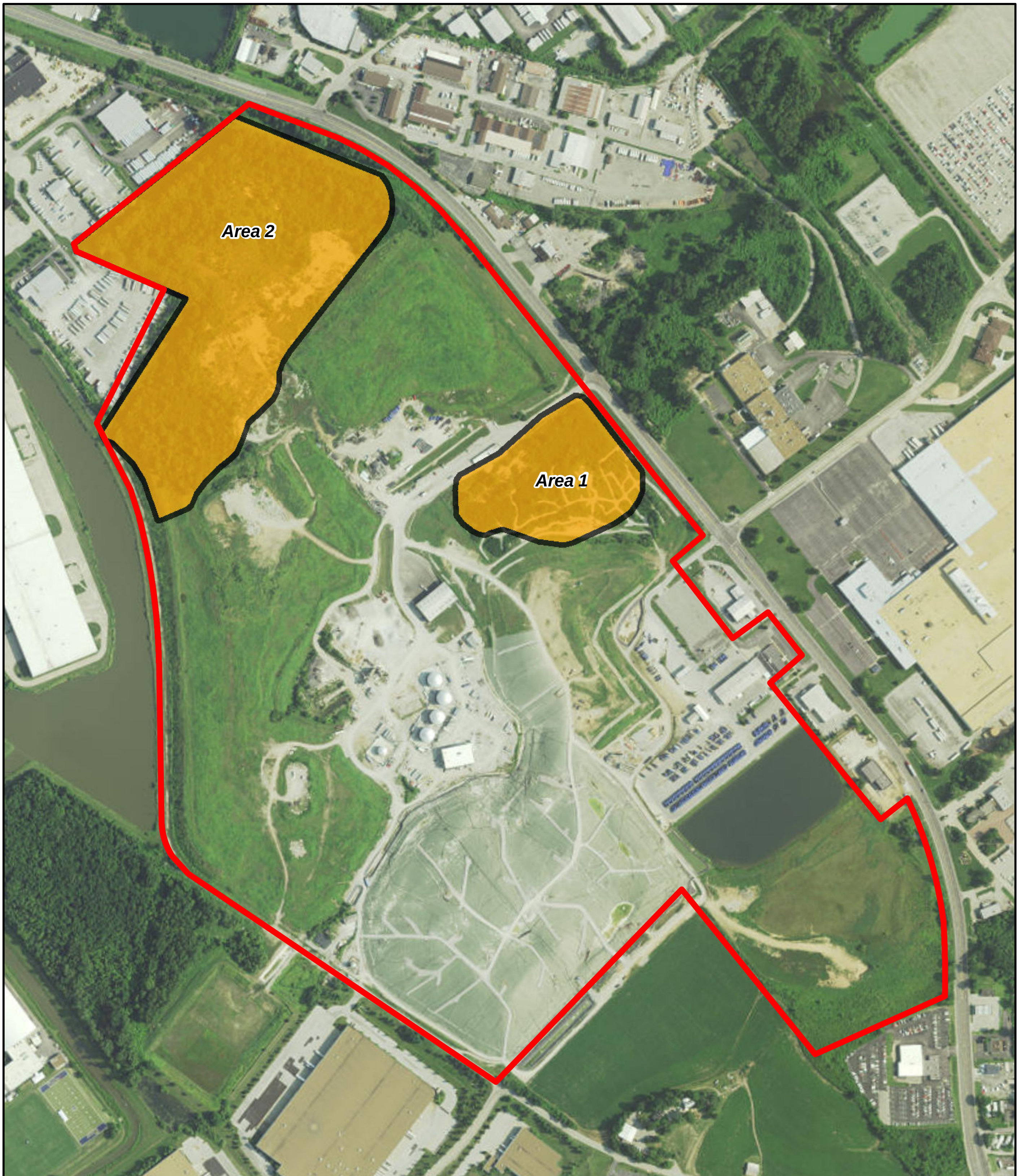
Argonne National Laboratory. 1993. Data Collection Handbook to Support Modeling Impacts of Radioactive Material in Soil. April.

Garver, E. and M. Baskaran. 2004. "Effects of Heating on the Emanation Rate of Radon-222 from a Suite of Natural Minerals." *Applied Radiation and Isotopes*. Volume 61.

Strong, K. and D. Levins. 1982. "Effect of Moisture Content on Radon Emanation from Uranium Ore and Tailings." *Health Physics*, Volume 42, No. 1.

APPENDIX B

FIGURE



Legend

Bridgeton Landfill

West Lake Landfill Site Operable Unit 1 (radiological area)

N

0 350 700

Feet

Source: ESRI, ArcGIS Online, World Imagery, 2014

X:\G\9025\0058\000\Projects\mxd\102615\Figure1.mxd

West Lake Landfill OU-1
Bridgeton, Missouri

Figure 1
Site Layout

TETRA TECH

Date: 10/26/15 Drawn By: Gustavo Orozco Project No: X9025.14.0058.000

APPENDIX C

ANALYTICAL LABORATORY PROCEDURE FOR DETERMINATION OF RADON EMANATION COEFFICIENT

Test and Analysis Plan for West Lake Smolder Event Samples

A. Discussion of Isotope Selection and Natural Occurring Radioisotope Decay Chains

The best starting point for verification of radioisotope selection is the inspection of a decay chain for each of the three main natural occurring radioisotopes, Uranium 238, Uranium 235 and Thorium 232. Copies of the decay chains are included as figures 2, 3 and 4 at the end of this this report. A brief discussion of interpretation of the chains is a follows: Isotopes are color coded based on their primary decay mechanism, Red for Alpha decay and Blue for beta decay. The half-life for each isotope is given in parenthesis. The branching percentage (the percentage of the time that an isotope decays by that mechanism) is given next to the alpha or beta symbol. Finally, a squiggle arrow next an isotope symbol indicates that an isotope has a useful gamma ray that can be used for analysis. An important property of radiation decay is secular equilibrium. Secular equilibrium occurs when a long lived parent isotope produces a much shorter lived daughter isotope and the daughter isotopes in-grows until its activity is the same as the parent. The most appropriate example of this is Radium 226, decaying into Radon 222. After 10 Radon 222 half-lives (38.2 days), the activity of Radon is the same as that of its parent Radium. This means that one can measure the radon activity and know the radium activity and visa-versa. This effect can continue down the chain, such that (see figure 2) Lead 214 and Bismuth 214 will also be in equilibrium, and can be used to measure the activity of radium and all of her daughters. Secular equilibrium means one only has to analyze either the parent or a single daughter to determine the activity of all daughters and the parent isotope, allowing the use of the most sensitive and selective method. Table1 shows the ingrowth and decay of any isotope based on the number of half-lives that have elapsed. Secular equilibrium does NOT work when the parent and daughter have similar half-lives such as Uranium 234 and Thorium 230. In this case, by the time the Thorium would reach equilibrium, the Uranium will have significantly decayed, although they would eventually reach equilibrium, there is a great deal of time (hundreds of thousands of years) when they would not be in equilibrium. In this case, no inference of the activity between parent and daughter can be done, necessitating the analysis of both parent and daughter. This is also true when a short lived parent decays into a long lived daughter such as Protactinium 234 decaying into Uranium 234. Equilibrium can also be upset by breaking the decay chain by physically removing a parent or daughter. In the example of Radium and Radon, since Radon is a gas, if the sample is purged, removing the radon before it has time to decay, then the chain will be broken and none of the daughters will be present in the sample. The same number of daughters and total activity will be produced, it is just that they will be physical removed from the original sample location. This can also occur if water flows through a sample and the chemistry is such that for example, Uranium is dissolved but Radium is left behind. This is the exact issue with Uranium mill tailings, the Uranium was removed to be used but all the associated Radium was left behind.

Table 1-Decay/Ingrowth

# of ½ Lives	Decay	Ingrowth
0	100.0%	0.0%
1	50.0%	50.0%
2	25.0%	75.0%
3	12.5%	87.5%
4	6.3%	93.8%
5	3.1%	96.9%
6	1.6%	98.4%
7	0.8%	99.2%
8	0.4%	99.6%
9	0.2%	99.8%
10	0.1%	99.9%

B. Confirmation of Radioisotopes Selected for Analysis

Based upon the prior discussion and evaluation of the Uranium 238 decay chain, the following isotopes should be considered for analysis: Uranium 238, Uranium 234, Thorium 230, Radium 226(directly or from daughters), and Lead 210. Evaluation of the Uranium 235 chain, the following isotopes should be considered for analysis: Uranium 235, Protactinium 231, and Actinium 227 (from daughters). Evaluation of the Thorium 232 chain, the following isotopes should be considered for analysis: Thorium 232, Radium 228 (from Actinium 228 daughter), and Thorium 228. The analysis of these isotope will enable the determination of all daughters in a decay series either directly or based on secular equilibrium.

C. Analytical Method selection

Four main methods are being evaluated for radiochemical analysis of the bulk samples, one method for moisture saturation/ release curves, and one method for standard chemical analysis. These methods are inductively coupled plasma mass spectrometry (ICP-MS), alpha spectrometry, gamma spectrometry, radon emanation, thermogravimetric analysis (TGA), and inductively coupled plasma atomic emission spectroscopy (ICP-AES). A brief description of each method is presented below.

1. **ICP-MS** – The sample is acid digested to solubilize the desired analyte and the digestate introduced by nebulization into an inductively coupled plasma which decomposes any compounds into their molecular or elemental state. During decomposition the elements are ionized, i.e. $UO_2 \rightarrow U \rightarrow U^+$, and the ions passed into a mass spectrometer where the signal is proportional to concentration. By comparing the signal of the sample to the signal from reference standards, the amount of the analyte can be calculated. It should be noted that since the technique uses a mass spectrometer for detection, the instrument measures individual isotope concentrations not total elemental concentrations. This allows the determination of not just the elemental concentration but also the isotopic composition, for example, allowing the measurement of all three Uranium isotopes (234, 235 and 238) not just the total Uranium concentration.

2. **Alpha Spectrometry** – The sample is acid digested to solubilize the desired analyte and the target analyte chemically separated and purified via ion exchange. The purified analyte is prepared for counting via process called mounting, where the analyte is put in a preferred geometry designed to allow the alpha particles to quantitatively escape, to be vacuum stable and in a size optimized for the equipment being used. The mounted sample is placed in close proximity to the alpha detector and both the sample and detector are usually in a vacuum chamber, which is evacuated during counting. The close proximity to the detector, vacuum and special mounting procedures are necessary due to the nature of alpha particles being very easy to shield, even by a small amount of air. The alpha particles interact with the detector and generate a distribution based on kinetic energy of the alpha particle and number of alpha at that energy. Since the energy of an alpha particle is diagnostic of the isotope from which it came, measuring the number of detections from a given energy allows the determination of the activity of that isotope in the sample.

3. **Gamma Spectrometry** – This technique allows sample analysis with little or no sample preparation. The sample is counted in bulk. Samples are placed in a bulk container and place directly in close proximity to the gamma detector. Solid samples are placed in gas tight containers to prevent radon gas from escaping, allowing the in-growth radon daughters. The gamma photons interact with the detector and generate a distribution based on the energy of the photon and number of photons at that energy. Since the energy of a gamma photon is diagnostic of the isotope from which it came, measuring the number of detections from a given energy allows the determination of the activity of that isotope in the sample.

4. **Radon Emanation** – An aliquot of soil, or a column of soil if measuring radon diffusion, is sealed in a container and purged of radon using gas (air, N_2, etc.), that has been stored long enough to allow any radon in the gas to decay (see table 1, 7 half-lives, 28 days, for 99% reduction). The sample container is sealed, and stored long enough for radon to in-grow (See table 1). If the sample is not held long enough for full in-growth, the activity is corrected based on the in-growth factor. The gas headspace is mixed well and the headspace gas, including any radon, purged into an evacuated Lucas cell. A Lucas cell is a vacuum chamber with an optical window and all other surfaces coated with a special substance that glows when hit by alpha radiation. The flashes of light are counted by a photomultiplier tube and are proportional to the amount of radon in the gas sample. The data are corrected for Radon in-growth in the sample, Radon decay during sampling and counting and the in-growth of Alpha emitting Radon daughters.

5. **Thermogravimetric Analysis** – This technique uses a highly sensitive balance to monitor the weight loss of a sample vs temperature. TGA also collects heat flow information to determine whether events are endothermic or exothermic. This will allow the determination of the moisture release curve of the sample to help determine the moisture content that samples should be tested at.

6. **ICP-AES** – The sample is acid digested to solubilize the desired analyte and the digestate introduced by nebulization into an inductively coupled plasma, which decomposes any compounds into their molecular or elemental state. During decomposition the elements are

ionized, and the ions give off their characteristic wavelength of light. The intensity of this light is proportional to the concentration of the element in the sample. By comparing the signal of the sample to the signal from reference standards, the amount of the analyte can be calculated.

D. Bulk Analysis

Samples will be analyzed for the isotopes via the methods found in table 2, it also includes the expected minimum detectible activity for each method/isotope. The five methods will ensure complete coverage of the entire Uranium 235 and 238 decay chains plus coverage of the Thorium chain with no additional effort and a metals determination to allow mass balance calculations for the sample to be verified. Gamma spectrometry will be performed immediately after preparing the sample aliquot and at a later time interval at least 4 days later to allow estimation of both radon in-growth rate as well as the calculation of end point in-growth of decay daughters of Radium. The radon emanation coefficient will be determined for the bulk sample as part of the thermal testing.

Table 2-Bulk Sample Tests and MDA's

Technique	Isotope	Estimated MDA pCi/gm
Gamma Spectrometry	Thallium 208	0.2
	Lead 210	5
	Bismuth 211	1
	Lead 211	5
	Bismuth 212	5
	Lead 212	0.5
	Bismuth 214	0.5
	Lead 214	0.5
	Radon 219	1
	Radium 223	1
	Radium 224	5
	Thorium 227	1
	Actinium 228	1
	Thorium 228	10
	Protactinium 231	5
	Thorium 231	2
	Protactinium 234	0.5
	Thorium 234	5
Alpha Spectrometry Isotopic Thorium	Thorium 228	0.1
	Thorium 230	0.1
	Thorium 232	0.1
Alpha Spectrometry Radium	Radium 226	0.1
ICP-MS Isotopic Uranium	Uranium 234	2
	Uranium 235	0.001
	Uranium 238	0.001
	Total Uranium	0.1 ng/gm
Radon Emanation	Radon Emanation Coefficient	0.002**
Thermogravimetric Analysis (TGA)	TGA Curve	n/a
ICP-AES	Total Metals	LAB RL's (See Table 9)

** MDA of test, actual coefficient RL dependent on initial Radium Activity

E. Radon Emanation

The radon emanation coefficient will be measured on sample aliquots before and after thermal treatment and at several different moisture contents. The sample "as received" will be carefully homogenized before any aliquots are taken. The radon emanation rate will be determined on samples that have been subjected to several different thermal treatments as well as had their moisture content adjusted. A description of the treatment and moisture contents are shown in table 3. The exact moisture content points will be determined after evaluation of the TGA curve, saturation point, and as received moisture content. Radon emanation ingrowth and measurement will be done with the samples at laboratory temperature after any pre-treatment. A minimum 50 gram aliquot of the bulk sample will be weighed into the emanation chamber (a 500ml round bottom flask, see figure 1). During the purging period prior to in-growth, the relative humidity of the purge gas will be adjusted to fit the moisture saturation of the samples, to prevent gross changes in the soil moisture content. The purge gas will be dry for any sample run at a saturation point less than 30%, and the purge gas will be humidified by running it through a bubbler for saturations greater 30%. Following purging, the chamber will be sealed and left to in-grow at least 20 days (95% in-growth, see table 1). After the in-growth period, the head space gas is well mixed and a gas aliquot introduced into a Lucas cell. The Lucas cell is held a few hours for radon daughter in-growth and counted to determine radon activity. In the event that the radon flux is high, a smaller sub aliquot of the well mixed headspace will be introduced into the Lucas cell. After all radon measurements are completed, a sub sample of the emanation aliquot will be analyzed via gamma spectroscopy to confirm Radium 226 content actually present in the sample used for radon measurement and confirm the level of homogeneity of the sample. Figure 5 contains a flow chart outlining the number of tests and conditions used.

Table 3-Thermal Test Conditions

Sample Treatment	Moisture Saturation (relative)
None ("As Received")	"As Received"
None ("As Received")	100% (Saturated)
Heated 105°C 16 hours	"As Found" After Treatment
Heated 250°C 16 hours	"As Found" After Treatment
Heat 60°C until at or below desired saturation	TBD from TGA (5% Est)
Heat 60°C until at or below desired Saturation	TBD from TGA (10% Est)
Heated 250°C 48 hours	"As Found" After Treatment
Heated 250°C 48 hours	"As Received"
Heated 250°C 48 hours	TBD (10% Est)

Figure 1- Emanation Apparatus

F. Quality Assurance

The samples will be analyzed on an as received basis. Each sample will be carefully homogenized thoroughly before aliquots taken for analysis. A duplicate sample will be analyzed for each method/preparation technique/matrix. Matrix spikes will not be available for air samples since there is no way to generate them. Tables 6-8 contain the basic quality control data to be run for each method type, i.e. Gamma Spectrometry, Alpha spectrometry ICP-MS etc.

Table 4-Gamma Spectrometry and Radon Emanation QC Checks

QC Check	Minimum Frequency	Acceptance Criteria	Corrective Action	Flagging Criteria
Method Blank	One per Method	No analytes detected > 2 times the blank Combined Standard Uncertainty (CSU). Blank result must not otherwise affect sample results.	Recount the blank to confirm results, unless all sample results are >5 times the blank activity.	If reanalysis cannot be performed, data must be qualified and explained in the case narrative. Apply B-flag to all results for the specific analyte(s) in all samples in the associated preparatory batch.
Lab Control Sample	One per Method. Low, Medium and High Energy. (i.e. Am-241, Cs-137, Co-60) for gamma; One Alpha and one Beta for Gross Alpha/Beta; Radium 226 in equilibrium for Radon emanation.	75-125% Recovery	Recount the LCS to confirm results. Inspect LCS control chart for indication of significant bias.	If reanalysis cannot be performed, data must be qualified and explained in the case narrative. Apply Q-flag to specific nuclide(s) in all samples in the associated preparatory batch.
Sample Duplicate	One per Method.	The duplicate error ratio (DER) between the sample and the duplicate is <3; or the relative percent difference (RPD) is <25%.	Contact Client for Discussion	For the specific nuclide(s) in the parent sample, apply J-flag if acceptance criteria are not met.

Table 5-Alpha Spectrometry QC Checks

QC Check	Minimum Frequency	Acceptance Criteria	Corrective Action	Flagging Criteria
Method Blank	One per Method.	No analytes detected > 2 times the blank Combined Standard Uncertainty (CSU). Blank result must not otherwise affect sample results.	Recount the blank to confirm results, unless all sample results are >5 times the blank activity.	If reanalysis cannot be performed, data must be qualified and explained in the case narrative. Apply B-flag to all results for the specific analyte(s) in all samples in the associated preparatory batch.
Lab Control Sample	One per Method. At least one isotope of the group (i.e. Th-232 for isotopic Thorium)	75-125% Recovery	Recount the LCS to confirm results. Inspect LCS control chart for indication of significant bias.	If reanalysis cannot be performed, data must be qualified and explained in the case narrative. Apply Q-flag to specific nuclide(s) in all samples in the associated preparatory batch.
Sample Duplicate	One per Method.	The duplicate error ratio (DER) between the sample and the duplicate is <3; or the relative percent difference (RPD) is <25%.	Contact Client for Discussion	For the specific nuclide(s) in the parent sample, apply J-flag if acceptance criteria are not met.
Matrix Spikes	One per preparatory batch. (MS not required when chemical yield tracers or carriers are employed).	If activity of the MS > 5 times the unspiked sample, Within 60-140% recovery.	Contact the client as to additional measures to be taken.	For the specific nuclide(s) in the parent sample, apply J-flag if acceptance criteria are not met.
Tracers (if used)	Added to each sample as isotopic yield monitor.	Isotopic yield within 30-110%. FWHM <100 keV and peak energy within ±40 keV of known peak energy.	Reanalysis of sample, including sample preparation.	For the specific nuclide(s) in the parent sample, apply J-flag if acceptance criteria are not met.
Carriers (if used)	Added to each sample as chemical yield monitor.	Chemical yield within 30-110%.	Reanalysis of sample, including sample preparation.	For the specific nuclide(s) in the parent sample, apply J-flag if acceptance criteria are not met.

Table 6-ICP, ICP-MS and IC QC Checks

QC Check	Minimum Frequency	Acceptance Criteria	Corrective Action	Flagging Criteria
Method Blank	One per Method.	No analytes detected > Reporting Limit. Blank result must not otherwise affect sample results.	Reanalyze samples, unless all sample results are >10 times the blank results.	If reanalysis cannot be performed, data must be qualified and explained in the case narrative. Apply B-flag to all results for the specific analyte(s) in all samples in the associated preparatory batch.
Lab Control Sample	One per Method. At least one isotope of a isotopic group (i.e. U-238 for isotopic Uranium)	80-120% Recovery	Reanalyze the LCS to confirm results. Re-prepare the samples.	If reanalysis cannot be performed, data must be qualified and explained in the case narrative. Apply Q-flag to specific analyte(s) in all samples in the associated preparatory batch.
Sample Duplicate	One per Method.	Relative percent difference (RPD) is <20%.	Contact Client for Discussion	For the specific analytes in the parent sample, apply J-flag if acceptance criteria are not met.
Matrix Spikes	One per preparatory batch.	If concentration of the MS > 5 times the unspiked sample, Within 75-125% recovery.	Contact the client as to additional measures to be taken.	For the specific analytes in the parent sample, apply J-flag if acceptance criteria are not met.
Post Digestion Spike	One per preparatory batch if MS fails or if unable to generate a MS due to limited sample.	If concentration of the MS > 5 times the unspiked sample, Within 80-120% recovery.	Contact the client as to additional measures to be taken.	For the specific analytes in the parent sample, apply J-flag if acceptance criteria are not met.

Table 7-ICP Laboratory Reporting Limits

Analyte	Water RL mg/L	Soil RL mg/kg	Filter RL ug/filter**
Ag	0.01	1	2.5
Al	0.1	10	25
As	0.01	1	2.5
B	0.04	4	10
Ba	0.005	0.5	1.25
Be	0.005	0.5	1.25
Bi	0.02	2	5
Ca	0.1	10	25
Cd	0.005	0.5	1.25
Co	0.005	0.5	1.25
Cr	0.005	0.5	1.25
Cu	0.005	0.5	1.25
Fe	0.1	10	25
K	0.25	25	62.5
La	0.01	1	2.5
Li	0.01	1	2.5
Mg	0.05	5	12.5
Mn	0.005	0.5	1.25
Mo	0.005	0.5	1.25
Na	0.25	25	62.5
Ni	0.005	0.5	1.25
P	0.05	5	12.5
Pb	0.005	0.5	1.25
Pd	0.02	2	5
S	0.05	5	12.5
Sb	0.02	2	5
Se	0.01	1	2.5
Si	0.1	10	25
Sn	0.01	1	2.5
Sr	0.005	0.5	1.25
Ti	0.005	0.5	1.25
Tl	0.02	2	5
V	0.005	0.5	1.25
W	0.02	2	5
Y	0.005	0.5	1.25
Zn	0.005	0.5	1.25
Zr	0.005	0.5	1.25

** Assumes 1/5 of filter taken for analysis

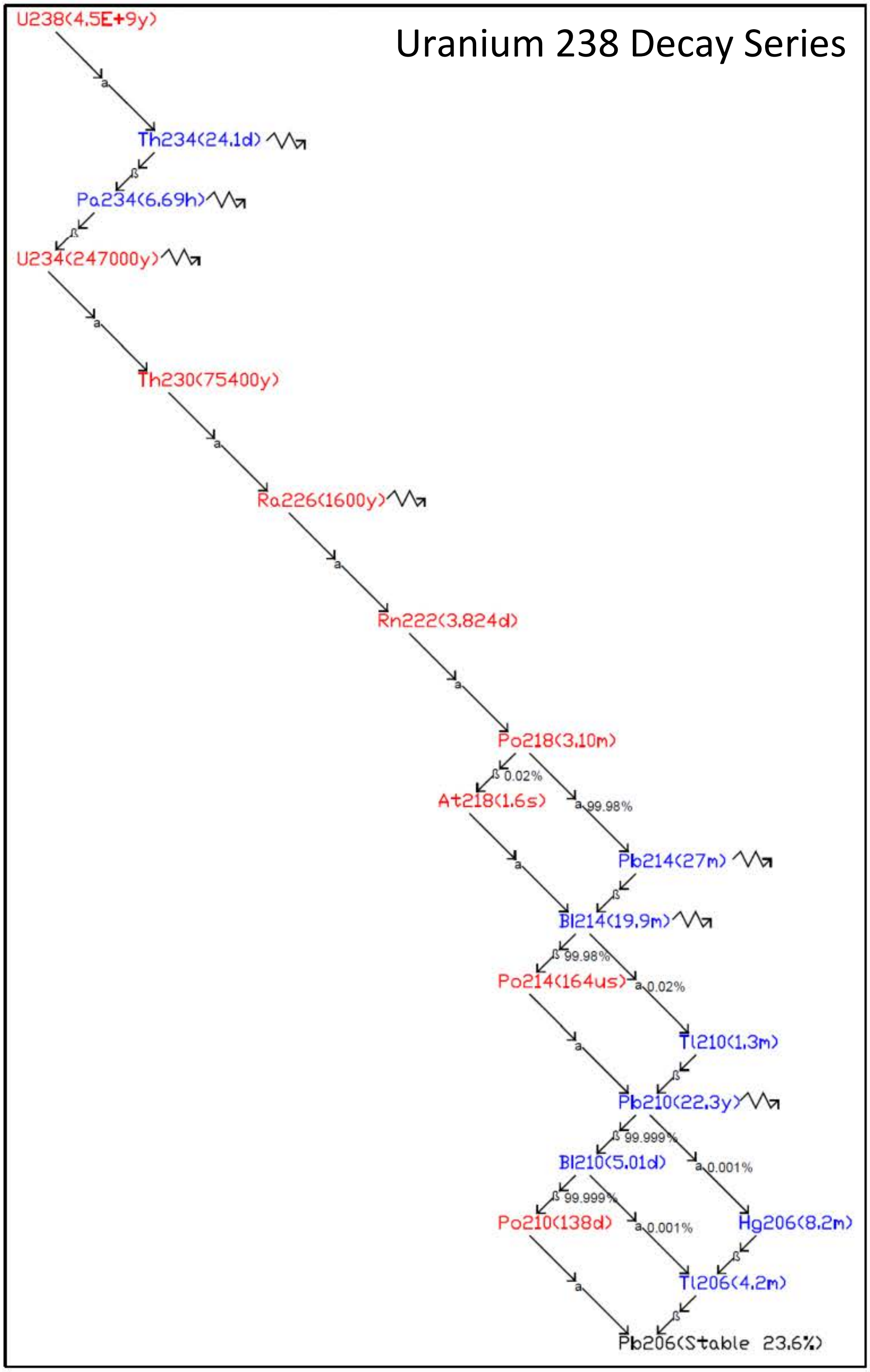


Figure 2-Uranium 238 Decay Chain

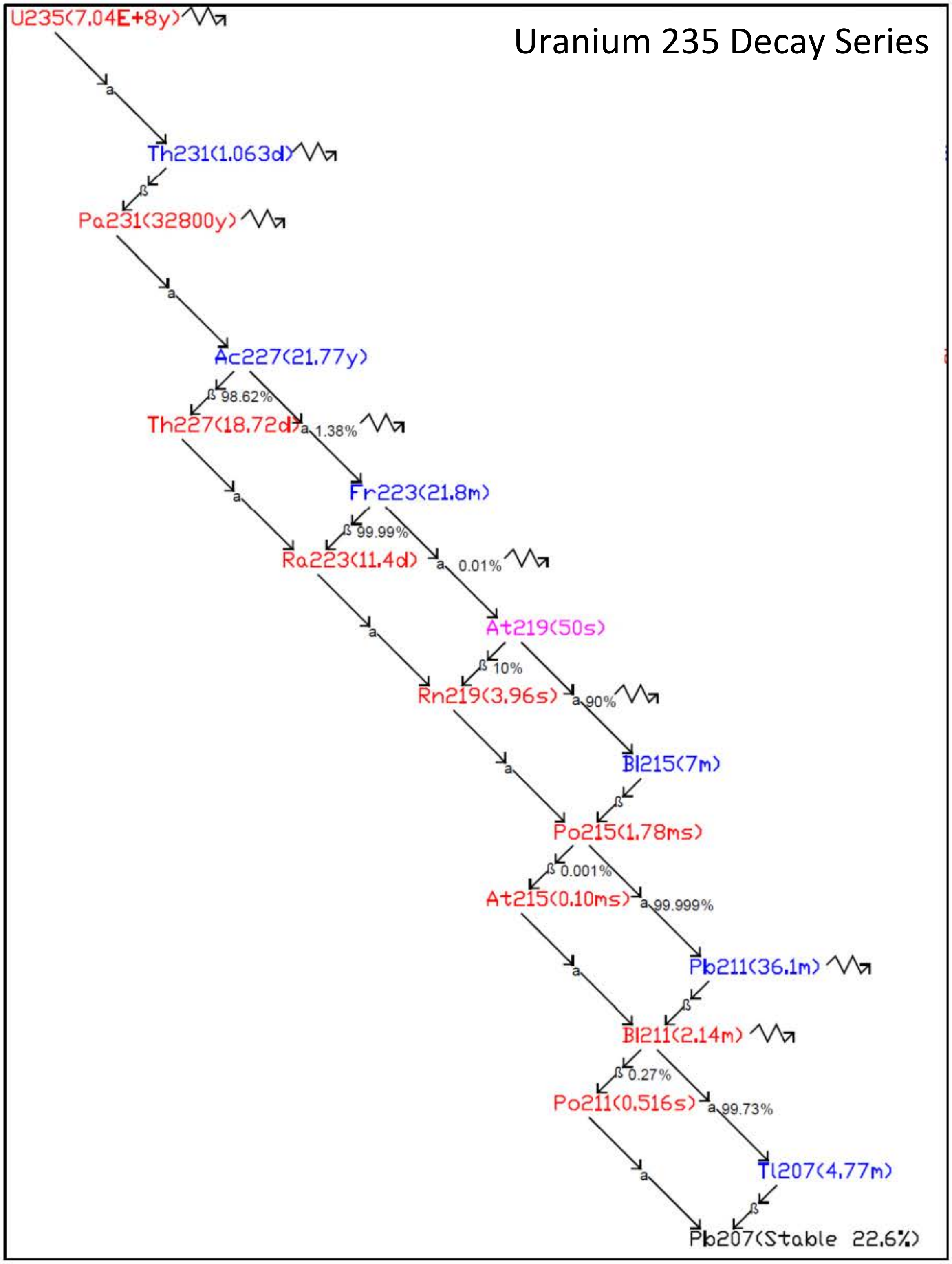


Figure 3-Uranium 235 Decay Chain

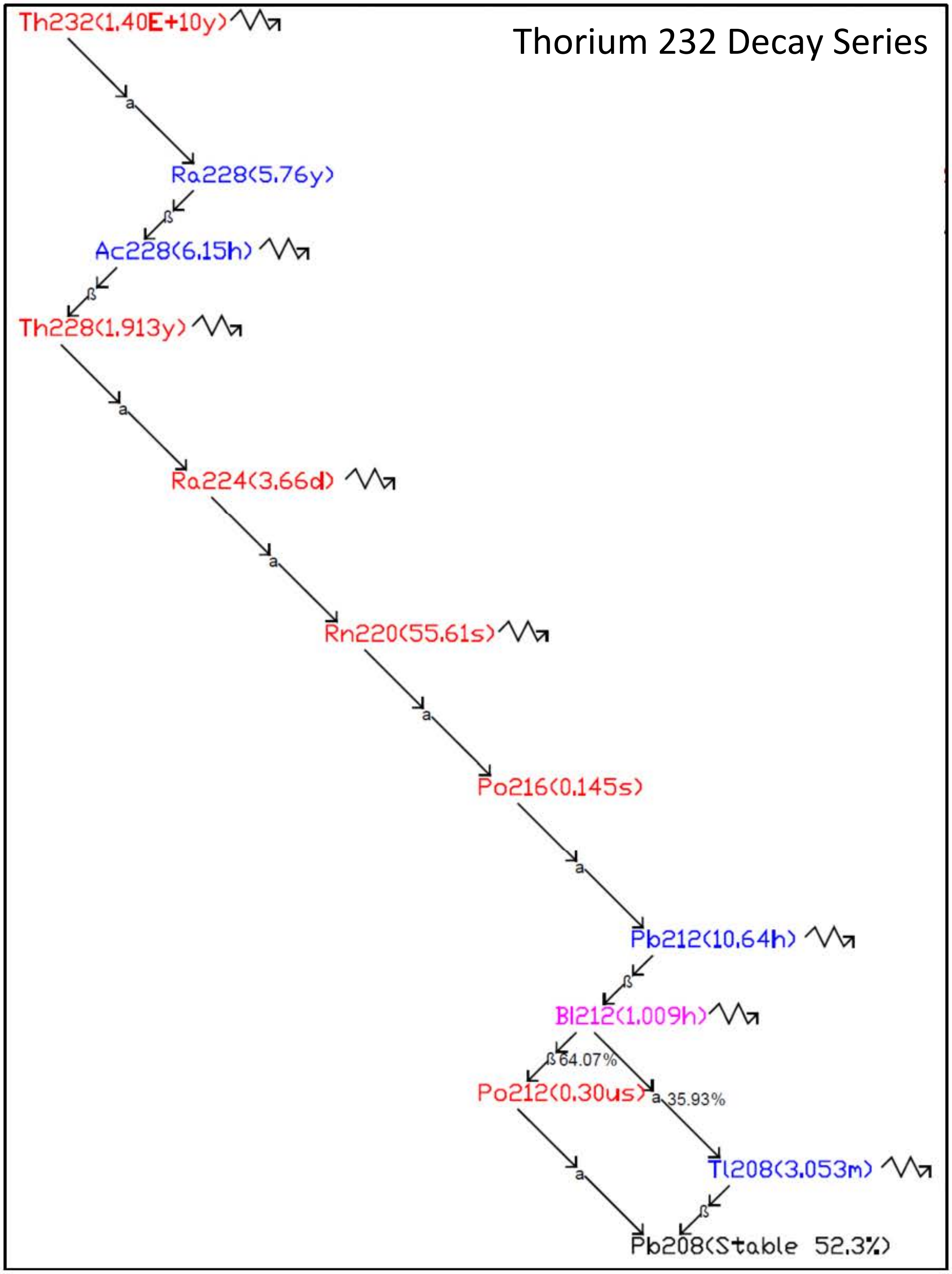


Figure 4-Thorium Decay Chain

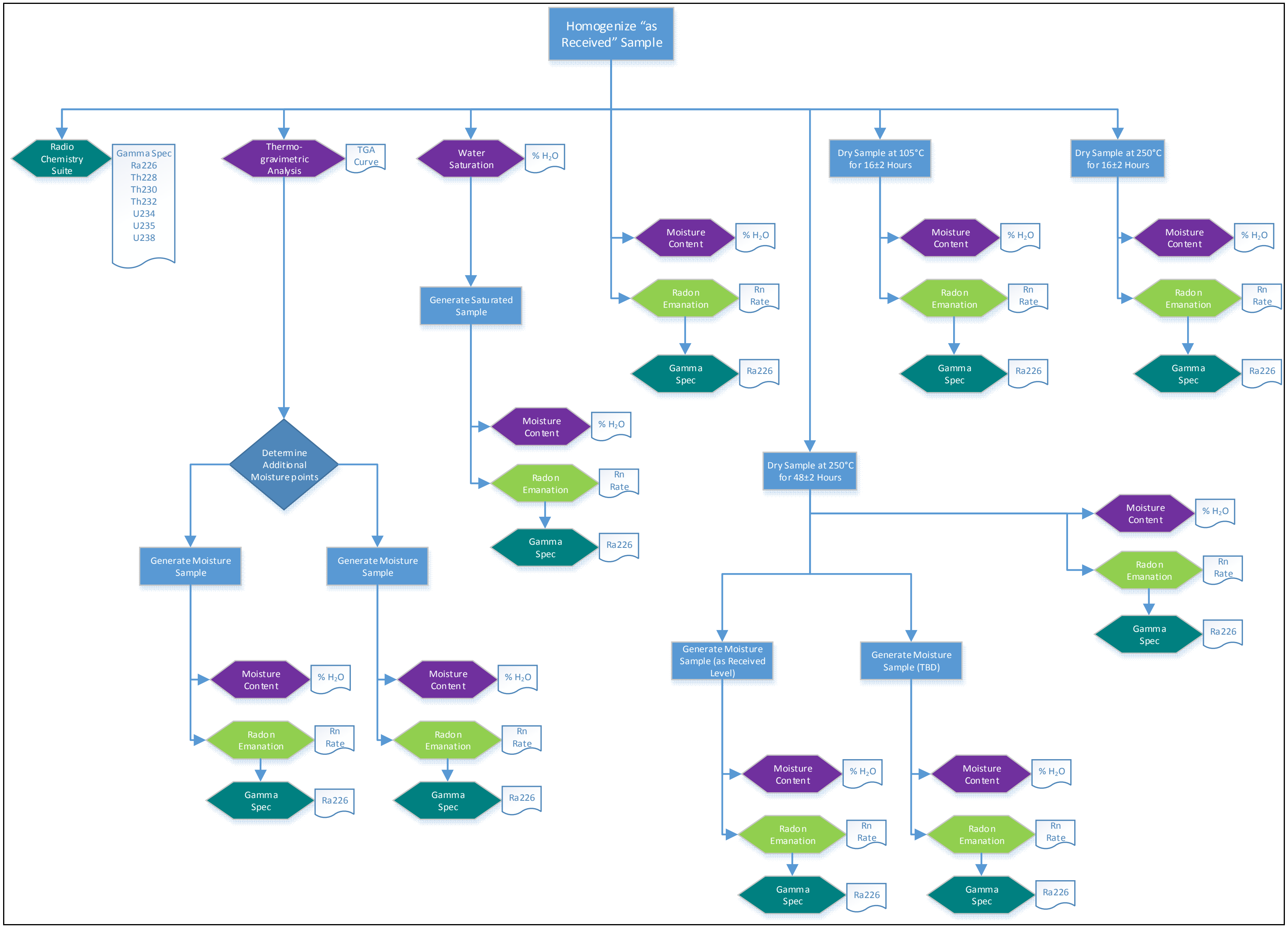


Figure 5- Emanation Flow Chart