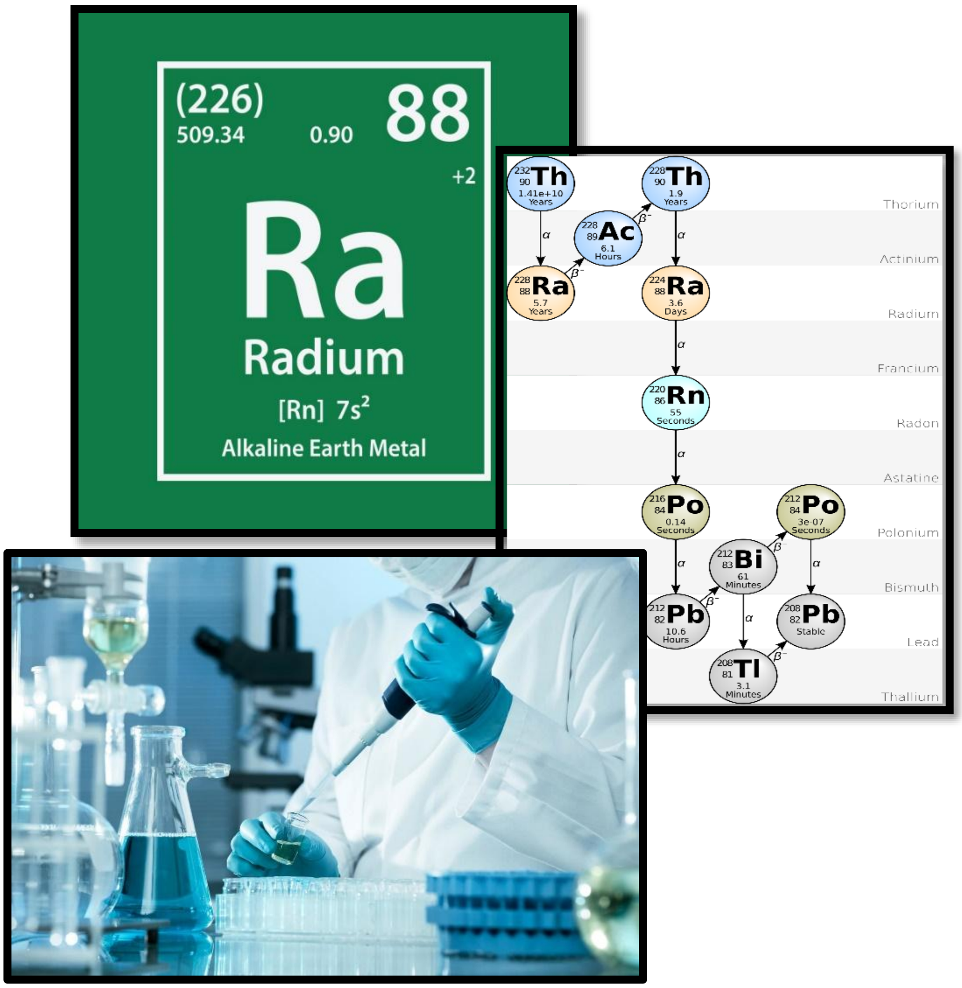

RADIUM IN UNTREATED LANDFILL LEACHATE INVESTIGATION

Pennsylvania Department of Environmental Protection

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Executive Summary

In 2021, the Pennsylvania Department of Environmental Protection (DEP) launched an investigation in collaboration with the Environmental Research and Education Foundation (EREF), and in cooperation with the Pennsylvania Waste Industries Association (PWIA), to characterize radiological constituents of concern potentially present in untreated landfill leachate. A total of 49 solid waste landfills in Pennsylvania permitted to receive municipal, residual, sanitary, and construction/demolition debris were included in this investigation. Samples of raw, untreated leachate were collected quarterly from each landfill and analyzed for total radium concentration.

- None of the untreated leachate from the 49 landfills in Pennsylvania exceeded the very conservative 600 picocuries per liter (pCi/L) annual average radium limit set by the US Nuclear Regulatory Commission (NRC). This limit applies to untreated wastewater from facilities NRC licenses to use radioactive material.

- Radium concentrations in the untreated leachate exceeded the U.S. Environmental Protection Agency's (EPA) drinking water limits for combined Radium-226 and Radium-228 of 5 pCi/L at less than a quarter of the landfills.

- DEP found no correlation between radium levels above 5 pCi/L and the acceptance of oil and gas waste at the landfill.

These results are in line with the findings from a 2016 major study undertaken by DEP, referred to as the 2016 TENORM study. In both, radium levels in untreated leachate were uniformly found to be lower than the NRC radium limit of 600 pCi/L. Because landfill leachate is subject to further treatment before discharging to the environment, DEP can conclude that there is currently no concern with the levels of combined radium in discharges of treated landfill leachate to groundwater or surface waters in the Commonwealth.

The EPA drinking water limit for combined radium concentrations is 5 pCi/L. Because landfill leachate is wastewater that is subject to further treatment and not directly consumed by humans, comparison to wastewater limits is more appropriate. The NRC sets public radiation exposure limits and environmental clean-up standards for licensed radioactive material. The NRC has established a 600 pCi/L annual average discharge limit for wastewater discharges from a facility licensed to use radioactive material. This is the limit for wastewater that is directed to treatment plants, such as those at municipal sewage systems, industrial facilities, and landfills. This NRC discharge limit is not the standard for combined radium in drinking water but is still based on the assumption that wastewater is ingested continuously by a human for an entire year. Based on the "as-low-as-reasonably-achievable" philosophy employed in radiation protection, this limit is extremely conservative and protective of human health.

Landfill leachate from each facility was tested quarterly using a test known as gamma spectroscopy. Due to the margin of error associated with gamma spectroscopy, each facility was also tested once utilizing radiochemistry analysis, an analysis that is much more accurate but used sparingly because of its expense.

In the 8-quarters of testing, none of the 49 landfills in Pennsylvania exceeded the NRC annual average of 600 pCi/L when using either test method – gamma spectroscopy or radiochemistry. Even when the maximum amount of error was added to the reported result, there is no exceedance of the NRC limit. Further, the radiochemistry results show that only 11 of the 49 landfills had radium in their untreated leachate above EPA's drinking water limit of 5 pCi/L for combined radium.

DEP found no correlation between the slightly higher radium levels and the acceptance of oil and gas waste at the landfill. Out of the 11 landfills with radiochemistry results above 5 pCi/L combined radium, only 4 had reportedly received oil and gas waste between 2015 and June 2024.

I. Introduction

Radiation in the Environment

Background radiation is the radiation that exists in the natural environment. Natural background radiation is all around us, all the time. Some radionuclides have been present in rocks since the formation of the Earth. According to the US EPA[1], natural background radiation comprises over half of our yearly exposure to radiation and can differ based on geographical location. The amount of background radiation that any one person receives depends on many factors, including radionuclides present in the Earth's crust, radionuclides created by cosmic rays hitting atoms in Earth's atmosphere, human activity and industry, including byproducts and wastes from industrial processes like mineral mining and milling, and the weather, which can cause radionuclides from past nuclear weapons testing to settle back to Earth from the atmosphere.

All radionuclides go through radioactive decay until they reach a stable state. Radioactive decay is the process in which a radioactive element transforms to another element, releasing radiation in the process. Natural radionuclides found in the Earth's crust include uranium and thorium. As they decay, they become other radionuclides such as radium, which can end up naturally in soil, water and air. The most common isotopes of radium (chemical symbol Ra) are Ra-226 and Ra-228. Radium-226 is part of the uranium decay series, and radium-228 is a part of the thorium decay series.

In the natural environment, radium occurs at trace levels in virtually all rock, soil, water, plants and animals. In areas where radium concentrations in rocks and soils are higher at groundwater depths, the groundwater also typically has relatively higher radium content.

Just about everything contains some trace amount of radioactivity, and the earth is also continually exposed to cosmic radiation from space. Radioactive materials exist in soil, rocks, and water, including in Pennsylvania's natural geologic formations. For example, the Marcellus Shale formation underlies much of Pennsylvania, with the exception of southeastern Pennsylvania. The Pennsylvania Department of Conservation and Natural Resources (DCNR) has documented that Marcellus Shale can contain from 10 to 100 parts per million (ppm) uranium (U). Typical crustal U concentrations in the US average 3 ppm.

Levels of naturally occurring radium can be concentrated as part of an industrial process, including resource extraction activities, demolition, and ceramics manufacturing. When naturally occurring radioactive material that is not subject to regulation under the laws of the Commonwealth or Atomic Energy Act, whose radionuclide concentrations or potential for human exposure have been increased above levels encountered in the natural state by human activities, the material is defined as Technologically Enhanced Naturally Occurring Radioactive Materials (TENORM) in accordance with DEP's regulations. Natural gas exploration, extraction and production result in various types of materials that may contain TENORM or may be impacted by TENORM. These materials include drill cuttings, filter sock residuals, impoundment sludge, tank bottom sludge, pipe scale, wastewater treatment plant (WWTP) sludge, and soils. Drill cuttings are wastes brought to the surface during the drilling process. Filter sock residuals and WWTP sludge are generated during the processing of wastewaters generated by oil and gas (O&G) activities. Impoundment and tank bottom sludge accumulates as a result of solid material settling out of well site wastewater.

Regulatory Structure for Management of Residual Wastes

Pennsylvania has specific regulations and guidance for exploration and production wastes, which have been adopted under multiple DEP-program areas, including DEP's waste management and oil and gas programs. Wastes generated from crude oil and natural gas exploration and production are exempt from regulation as hazardous waste under Subtitle C of the Resource Conservation and Recovery Act (RCRA) and are generally subject to nonhazardous regulation under Subtitle D of RCRA and state regulations. Under Pennsylvania's regulatory framework, oil and gas-derived wastes are defined as "residual waste," as the term is defined in 25 Pa. Code, 287.1, and regulated as such in accordance with DEP's residual waste regulations.

Pennsylvania's residual waste regulations are among the most robust and protective non-hazardous waste management regulations in the nation. In addition to requiring specified transportation signage and providing provisions for the special handling and disposal of radioactive material, the residual waste regulations require all generators of waste to perform a chemical and physical characterization of wastes generated prior to transportation to a processing or disposal facility. In accordance with 25 Pa. Code §§ 287.51(b) and 287.54(a)(1), a person or municipality that generates more than 2,200 pounds of residual waste per generating location in any single month in the previous year must perform a detailed analysis fully characterizing the physical and chemical composition of each type of waste it generates, including radioactivity. When radioactive materials are identified in waste, the Federal Department of Transportation Regulations, Title 49 of the Code of Federal Regulations also require the waste to be characterized prior to transportation.

Pennsylvania landfills that are permitted to accept residual waste, including oil and gas-derived waste, must comply with the full breadth of Pennsylvania's residual waste management regulations. The landfills, while designated as Subtitle D facilities under RCRA, are constructed to meet RCRA Subtitle C standards. Pennsylvania's municipal and residual waste landfills are precluded by regulation from accepting liquid or hazardous waste, as the term is defined at 40 CFR 260.10, and incorporated by reference at 25 Pa, Code 260a.1. In addition, each landfill must have an approved waste acceptance plan that is specific to each facility and identifies concentration-based limits for individual constituents to ensure that each waste approved for acceptance can be adequately managed based on the facility's design. The blending of waste prior to disposal to 'dilute' the concentration of constituents is also prohibited.

DEP has the responsibility of protecting the health and safety of the citizens of the Commonwealth and the environment from exposure to toxic and hazardous materials, including most sources of radiation. In 2000, DEP required the installation of radiation monitors at all Pennsylvania waste management facilities. The monitors measure external gamma radiation levels in micro-roentgens per hour (μR/hr) and were required to preclude the disposal of acutely radioactive material that may be inappropriately or unintentionally mixed with regular solid waste. The monitors measure the radioactivity of every load of waste that comes to a landfill prior to the landfill being able to accept the waste for disposal. Shortly thereafter, DEP developed supporting guidance to allow landfills to accept TENORM for disposal provided certain limitations were not exceeded and DEP's protocols were followed. TENORM is not subject to any EPA or U.S. Nuclear Regulatory Commission (NRC) statutes, nor is it regulated by any federal agency or under DEP's Radiation Protection Program. However, when disposed of, TENORM is regulated under the Solid Waste Management Act and DEP's Bureau of Waste Management.

During the expansion of the Marcellus Shale Gas industry, DEP observed a steady increase in the volume of waste containing TENORM being disposed in Pennsylvania landfills. In practice, when the monitors measure radioactivity in a certain load of waste that measures 10 μR/hr above background, that waste load is investigated further by the landfill operator to identify the nature of the TENORM material and determine if it is acceptable for disposal. In some instances, where the material is unusual or has a high level of activity, the landfill operator will coordinate with DEP to determine its acceptability for disposal or if the material should be rejected. If the material is rejected, it is returned to the generator for proper shipment to a facility authorized to take the material. All TENORM-containing material that is accepted by landfills is recorded by the landfill operators and reported to DEP.

<u>Landfill Leachate Management</u>

Landfill leachate is liquid generated by the movement of precipitation through the disposed waste and by the compaction and decomposition of the waste itself. As liquid moves through the waste, contaminants are leached from the disposed material, may solubilize and migrate through the landfill via the leachate. Landfills are designed with a leachate collection system to ensure leachate does not enter the groundwater and is collected for treatment. Collected leachate must be subsequently treated by a permitted wastewater treatment operation. Upon meeting National Pollutant Discharge Elimination System (NPDES) water quality standards, the treated leachate may be discharged to a receiving body of water. Some landfills operate onsite treatment systems while others are connected to local publicly owned treatment works (POTWs), which treat landfill leachate prior to discharge. Because landfills accept oil and gas industry wastes, such as drill cuttings and treatment sludge that may contain TENORM, there is a potential for leachate from those facilities to also contain TENORM.

DEP has conducted several other investigations into potential radiological contamination associated with oil and gas-derived waste, including a large-scale investigatory study of TENORM in 2016 (2016 TENORM study), as well as testing of leachate from the Westmoreland Sanitary Landfill (WSL). In both cases, DEP or DEP-certified laboratories have analyzed leachate for radium-226 and radium-228. Samples taken of WSL's leachate showed radium levels far below federal action levels. The 2016 TENORM study did not identify significant differences between radium levels in leachate from landfills that accepted oil and gas-derived waste compared to those that do not. Testing results in all cases were lower than effluent limits for radium-226 and radium-228 established by the NRC. However, the 2016 TENORM study also concluded, in part, that additional evaluation of the potential for oil and gas-derived waste to radiologically impact landfill leachate was necessary.

II. Project Purpose, Scope and Methods

Since completion of the 2016 TENORM study, the presence of TENORM waste in landfills and the potential presence of radiation in landfill leachate has continued to be raised as a concern.

Following publication of the 2016 TENORM study, DEP took steps to address radiation concerns, including requiring Radiation Protection Action Plans for unconventional oil and gas operations that generate TENORM, developing a revised TENORM disposal protocol for landfills and application of enhanced tracking efforts for the landfill disposal of TENORM-containing waste. In follow up to the recommendation of the 2016 TENORM study to further evaluate landfill leachate, DEP initiated this study in 2021, testing for radium in landfill leachate as another step in DEP’s ongoing efforts to ensure a high degree of protection for public health, safety and the environment.

A total of 49 solid waste landfills in Pennsylvania that are designated for receipt of municipal, residual, sanitary, and construction/demolition debris were included in this study. These landfills feature leachate collection systems to capture liquids percolating through the landfill for subsequent treatment at a wastewater treatment facility or on-site leachate treatment plant. In Pennsylvania, landfills that generate leachate must collect and provide for the treatment of leachate prior to discharge into a receiving water. This obligation is met under two different scenarios:

1. Leachate is treated at a leachate treatment plant (LTP) that is co-located at the landfill. Treated leachate is discharged from the LTP to a receiving water under a NPDES permit.

2. Untreated leachate is transported by truck or conveyance to a POTW, which treats wastewater and discharges to a receiving water under a NPDES permit.

Figure 1 below shows landfill leachate management (onsite vs. discharge to POTW) and Figure 2 displays leachate treatment methods currently used at landfills. Of the landfills that participated in this project, approximately half have an onsite LTP and half send untreated leachate to a POTW for treatment. To inform future data gathering efforts and to provide information on the efficacy of various treatment options, information on the treatment used for all active solid waste landfills with leachate collection systems was compiled to facilitate future leachate monitoring decisions.

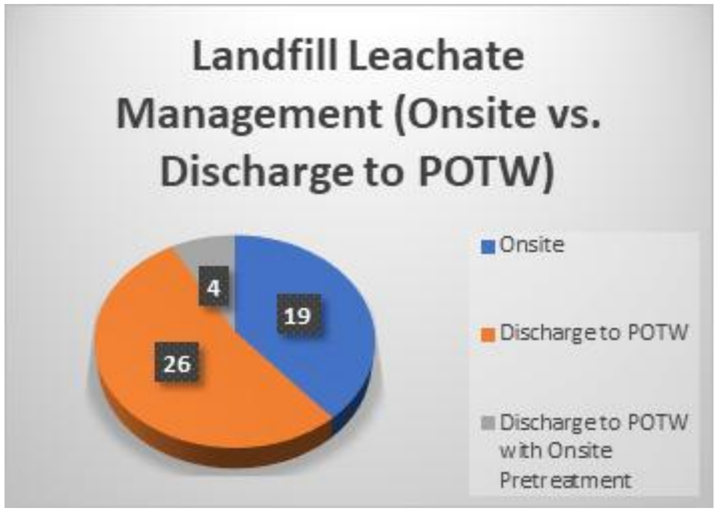

Figure 1

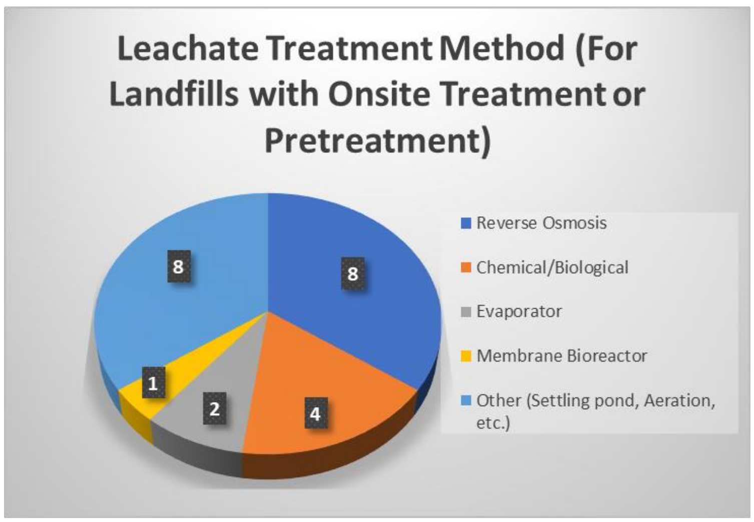

Figure 2

Active landfill operators are required by regulation to periodically sample and characterize their leachate for a suite of non-radioactive contaminants of concern. In partnering with industry stakeholders and external affiliates, DEP initiated this two-year study to evaluate untreated landfill leachate for Ra-226 and Ra-228. The study aimed to generate findings that either ensure existing regulations and protocols are functioning as intended or inform needed changes to testing regimes, disposal protocols and other engineering or operational controls that provide a high degree of protection to public health and the environment. The study was conducted in accordance with the General Methodology and Sampling and Analysis Plan, which contains a landfill key with landfill names and corresponding ID numbers, included as Appendix A.

All leachate samples generated during the investigation were analyzed by either Pace Analytical Services, LLC (Pace) or GEL Laboratories, LLC (GEL). All raw laboratory analytical results from Pace and GEL generated throughout the course of the 8-quarters of testing can be accessed in Appendices B and C. Both laboratories have extensive experience analyzing Chain of Custody agreements, are familiar with the sample matrices involved, maintain accreditation for and implement approved quality assurance programs to provide objective evidence that all measurements satisfy specific quality assurance objectives. The method utilized by both labs for sample analysis was EPA 901.1 (Gamma Emitting Radionuclides in Drinking Water), a method often referred to as "gamma spectroscopy." Gamma spectroscopy was chosen for the investigation based upon the cost effectiveness of the test method, the amount of radioactivity anticipated in the untreated leachate samples, and the established action levels for the investigation; however, a higher degree of uncertainty (a variable in a sample result that provides an indication of how accurate a sample result is) and higher detection limits (meaning a higher concentration could be needed to determine presence) are inherent in gamma spectroscopy compared to other test methods.

The two-year investigation commenced with sample collection on December 13, 2021, and sample collection activities were completed on September 27, 2023. All leachate samples collected from the landfills were of raw, unfiltered, untreated leachate from the leachate collection system. Samples were collected and packed for shipment by properly trained and qualified DEP staff and witnessed by authorized DEP representatives and landfill site representatives, as appropriate. Samples were collected using clean one-liter amber glass bottles along with additional quality control duplicate or triplicate samples in some predetermined instances. Trip blanks were unnecessary because no volatile organic compound analyses were included as part of the investigation. Performance evaluation samples (e.g., samples spiked with known concentrations of radionuclides in levels similar to those expected in the actual samples or blanks) were not prepared beyond those included in the laboratories' quality assurance plans to further document the accuracy and precision of their measurements process.

For purposes of assessing data generated during the investigation, DEP utilized an existing NRC established limit, displayed in Table 1, for facilities that discharge radium in effluent:

Table 1 – NRC Established Radium Discharge Limits

Type of Treatment	Average Annual Concentration of Total Radium (picocuries per liter, pCi/L)
Untreated or treated leachate discharges to any facility that treats and discharges wastewater, including STP[1] , LTP[2] , POTW[3] , or PrOTW[4]	600
Direct discharge of treated leachate to a body of water from a STP, LTP, POTW, or PrOTW	60
[1] Sewage Treatment Plant (STP) [2] Leachate Treatment Plant (LTP) [3] Publicly Owned Treatment Works (POTW) [4] Privately Owned Treatment Works (PrOTW)	

The 600 pCi/L is the regulatory effluent limit of the NRC set forth in 10 CFR 20 App. B[(2)] for a licensed facility, discharging radium to a STP or POTW. Though this value is not a direct regulatory requirement for landfills, it is an average annual concentration established to prevent a person from exceeding the public radiation dose limit. Leachate exhibiting an average annual concentration of total radium in excess of 600 pCi/L cannot be discharged to an offsite STP, LTP, POTW, or privately owned treatment works (PrOTW), and would require onsite treatment or would need to be sent to a facility permitted to accept liquid waste containing radium above 600 pCi/L. The 60 pCi/L effluent limit pertains specifically to *treated* leachate being directly discharged to a receiving body of water. Since this investigation involved the sampling and analysis of *untreated* leachate samples, the 600 pCi/L average annual concentration of total radium for landfills is appropriate for comparative purposes. It is worth noting that the basis for these NRC limits, which are not drinking water standards, are based on the assumption that the discharges are ingested continuously for an entire year in a manner that would result in a radioactive dose of 50 millirem to a member of the public. This 50 millirem value is *half* of the NRC's 100 millirem public dose limit for members of the public. Given that untreated landfill leachate is not being ingested, the NRC effluent limit of 600 pCi/L, which already takes into account the most restrictive annual limits on intake (in this case the amount of Ra-226 or Ra-228 that an individual can take into the body), is also conservative when used for a comparative measure for assessing environmental protection and human health and safety.

During the investigation, if any sample results had exceeded the action 600 pCi/ L action level by a factor of 2, or if the leachate results from a single landfill exceeded the action level for two (2) quarters consecutively, DEP would have worked with the impacted facility to take necessary action. Additionally, if the average annual radium concentration exceeded the action level based upon four consecutive quarters of data, DEP would have worked with the impacted facility to take necessary action. Throughout the sampling and ongoing evaluation of the data, DEP did not identify any levels of radiation associated with the investigation that raised concern for public health and safety or that required landfill action.

Modification of Methods

After three quarters of sampling and analysis, DEP realized that the margins of uncertainty and minimum detectable concentrations (MDC) for the sample results generated by gamma spectroscopy were higher than originally anticipated. The MDC is the lowest concentration of a substance, in this case Ra-226 and Ra-228, that a lab can confidently say is present. The margin of uncertainty is the range within which a lab can say that the true concentration of a substance lies. When the MDC and margins of uncertainty for a sample are high, the true concentration of a substance in that sample, especially if it exists in an extremely small concentration, cannot be confidently determined. To account for the uncertainties and high MDCs in the sample results, DEP took a conservative approach to data evaluation by summing the reported results for Ra-226 and Ra-228 or the MDC, whichever is greater, as well as the maximum amount of uncertainty associated with each isotope for comparison to the action level for the investigation. This approach caused DEP to evaluate the highest possible combination of sample results generated during the investigation as a “worst-case” scenario.

In addition, DEP opted to add a confirmatory test using a different, more accurate method called radiochemistry using EPA 903.1 (Radium-226 in Drinking Water Radon Emanation Technique) and Brooks and Blanchard (equivalent to EPA 904.0 Radium-228 in Drinking Water). These methods are more sensitive and accurate analytical methods in comparison to gamma spectroscopy. The radiochemistry samples were analyzed by DEP’s Bureau of Laboratories (BOL). DEP collected and analyzed at least one untreated leachate sample for total combined radium from each landfill using radiochemistry to verify that the gamma spectroscopy data definitively fell below the 600 pCi/L action level. All raw laboratory analytical results from radiochemistry testing can be accessed in Appendix D.

III. Results

Gamma Spectroscopy Results

Throughout the 8 quarters of sampling, at least one sample of landfill leachate was collected at each landfill during each quarter and analyzed for Ra-226 and Ra-228; basic scientific research protocols require duplicate and triplicate samples. Duplicate and triplicate samples were gathered and analyzed at specified intervals and through ad-hoc sampling, as determined by evaluation of sample results.

In an effort to present data in the most understandable and conservative manner, the highest combined radium result for each landfill during a given quarter was selected for further evaluation. This approach was chosen because it considers the highest possible Ra-226 and Ra-228 results in untreated landfill leachate for assessing whether there are any human health and safety or environmental safety concerns These values were considered throughout the course of the investigation for purposes of comparison to the established, aforementioned action levels.

For each sample, the laboratory data provided a result expressed in pCi/L, an uncertainty value, and an MDC for both Ra-226 and Ra-228. To determine the conservative combined radium result for each landfill, the uncertainty value for each Ra-226 and Ra-228 sample was added to the pCi/L result or the MDC, whichever was higher. The resulting values for Ra-

226 and Ra-228 were then added to generate a combined radium value for the sample, conservatively including the maximum reported uncertainty value.

Figure 3 provides an example of landfill leachate sample results for Ra-226 and Ra-228 and how the conservative combined radium result is determined:

Isotope	Results (Raw Data)	Uncertainty (±)	MDC	Reportable Results	Upper Bound Radium	Combined Radium Ra-226 & Ra-228 (Raw Values)	Units
Ra-226	102.21	49.209	42.12	102.21	151.419	315.4	pCi/L
Ra-228	29.14	46.965	117	<MDC	163.965		pCi/L

Figure 3

For Ra-226, the pCi/L result (102.21 pCi/L) was greater than the MDC (42.12 pCi/L), so the result was added to the uncertainty value (49.209) to determine the "upper bound" Ra-226 value of 151.419 pCi/L.

For Ra-228, the pCi/L result (29.14 pCi/L) was less than the MDC (117 pCi/L), so the MDC was added to the uncertainty value (46.965 pCi/L) to determine the "upper bound" Ra-228 value of 163.965 pCi/L.

The upper bound Ra-226 and Ra-228 values are then added to calculate the conservative combined radium result of 315.4 pCi/L.

Table 2, below, shows the highest conservative annual average combined radium value for each landfill during 4 consecutive quarters of sampling. It is important to reemphasize that the values shown in Table 2 are the highest average value for each landfill and are not conveying the true annual average for combined radium values in landfill's leachate, which are likely significantly lower. Unfortunately, the use of gamma spectroscopy as an analytical technique resulted in high uncertainty values and high MDCs for nearly every Ra-226 and Ra-228 sample throughout the course of the investigation, which limits the ability to accurately determine the true concentrations of Ra-226 and Ra-228 in untreated landfill leachate. A document showing summarized results information for each landfill throughout the 8-quarters of sampling, including the calculated conservative combined radium values can be accessed in Appendix E.

To provide some relative certainty from an environmental protection and human health and safety perspective, the gamma spectroscopy data was compared to the 600 pCi/L action level (the NRC discharge limit for average annual concentration of total radium) established for the investigation. Based upon the results conveyed in Table 2, the highest average annual conservative combined radium value from any one landfill statewide was 540.657 pCi/L. No landfill exceeded the 600 pCi/L average annual concentration limit. Even though the true levels of combined radium in landfill leachate are likely significantly lower than the average annual conservative concentrations contained in Table 2, the values illustrate that there is little concern with landfills exceeding the 600 pCi/L average annual concentration limit.

Table 2. Summary of Gamma Spectroscopy Results

Facility ID#	Highest Average Annual Combined Radium[1] (pCi/L) Over 4 Consecutive Quarters
26	308.969
21	309.158
29	322.318
41	325.990
37	329.438
48	331.089
43	332.917
39	336.601
45	337.863
3	338.244
15	339.446
4	340.572
36	344.458
23	345.151
46	347.094
33	348.933
17	350.044
12	350.636
18	352.746
5	352.788
7	353.522
30	353.677
19	354.505
22	358.888
11	359.782
44	360.467
27	361.150
20	362.026
31	362.992
13	365.479
16	372.011
35	372.411
9	382.427
34	384.473
32	387.813
14	389.538
2	391.972
10	392.521

Table 2. Continued

6	393.031
49	396.669
28	398.031
8	401.790
25	420.364
40	436.275
47	438.862
24	444.130
42	453.383
38	461.510
1	540.657
[1] Total combined radium is a conservative value that adds the uncertainty value for each Ra-226 and Ra-228 sample to either the pCi/L result or the MDC, whichever was greater, respectively.	

Radiochemistry Results

In contrast to the uncertainty and high detection limits associated with gamma spectroscopy, the radiochemistry values are more indicative of the true presence of radium. For consistency and to present data in the most understandable and conservative manner, the total combined radium result(s) analyzed through radiochemistry for each landfill were calculated the same way as the gamma spectroscopy results. In addition, while unconventional and abundantly conservative for data evaluation, this approach was utilized to ensure that decisions affecting public health, safety and the environment are made based on a "worst-case" scenario.

For each sample, the laboratory data provided a pCi/L result, an uncertainty value, and a minimum detectable amount (MDA) for both Ra-226 and Ra-228. To determine the conservative combined radium result for each landfill, the uncertainty value for each Ra-226 and Ra-228 sample was added to either the pCi/L result or the MDA, whichever was higher, respectively. The resulting values for Ra-226 and Ra-228 were then added to generate a conservative combined radium value.

Of the 49 landfill radiochemistry results, only 11 landfills had results that were above 5 pCi/L. This value is one part of the EPA radionuclide rule that limits the combined radium concentrations (Ra-226 plus Ra-228) to 5 pCi/L for community drinking water systems. It is important to keep in mind that only samples of untreated leachate were collected during the 8-quarter investigation. Comparison to the 5 pCi/L federal standard for combined Ra-226 and Ra-228 for compliance purposes is not appropriate for untreated landfill leachate as no person is ingesting landfill leachate. Subsequent treatment of untreated landfill leachate is always required prior to discharging to a receiving body of water. The treatment and discharge of all wastewaters, including landfill leachate is performed under the authority of a permit issued by DEP. The 5 pCi/L level is included here to illustrate the small amount of radium observed in the leachate when radiochemistry was used as the testing methodology.

Of the 11 landfills with radiochemistry results above 5 pCi/L combined radium, only 4 landfills reportedly received oil and gas waste between 2015 and June 2024 according to DEP's Oil and Gas Electronic Reporting (OGER) database information, and their results ranged from 5.346 to 8.025 pCi/L.

The remaining 7 landfills, which had radiochemistry results ranging from 5.779 – 122.731 pCi/L, were landfills that reported receiving no oil and gas waste between 2015 and June 2024 (one of these landfills did report receiving less than 10 tons of oil and gas waste, but this was viewed as a negligible amount).

Most of the remaining 7 landfills appear to be located in areas in Pennsylvania where the highest levels of near surface naturally occurring radiological isotopes exist. Natural background conditions could play a major role in explaining why these landfills, which do not receive oil and gas waste material, had higher radiochemistry results compared to other landfills, including those that do accept oil and gas waste for disposal.

Of the 23 landfills that reportedly received oil and gas waste between 2015 and June 2024 in amounts greater than 10 tons, the average radiochemistry result for combined Ra-226 and Ra-228 was 3.148 pCi/L (ranging from 1.523 pCi/L to – 8.025 pCi/L).

Of the 26 landfills that reportedly received no oil and gas waste between 2015 and June 2024, the average radiochemistry result for combined Ra-226 and Ra-228 was 15.836 pCi/L (ranging from 1.443 pCi/L to 122.731 pCi/L).

It is worth noting that in radiochemistry analysis, a negative sample result can occur when a sample has little radioactivity, and the analytical results show a normal distribution of positive and negative values around zero. This can happen when a sample value is less than that of the detector system's background.

Although radiochemistry provides more accurate results with significantly less margin of error compared to gamma spectroscopy, only one data point is available for combined radium for 47 landfills. Two landfills (landfill numbers 24 and 28) were sampled on one additional instance because they had the highest radiochemistry results from the initial round of radiochemistry sampling and analysis.

Table 3. – Summary of Radiochemistry Results

Facility ID#	Ra-226 (pCi/L)			Ra-228 (pCi/L)			Total Combined Radium[3] (pCi/L)
	Result	Uncertainty	MDA[1]	Result[2]	Uncertainty	MDA	
12	0.18	0.04	0.04	0.322	0.472	0.753	1.443
6	0.05	0.03	0.05	0.67	0.77	0.51	1.523
38	0.06	0.029	0.039	0.236	0.547	0.89	1.526
33	0.056	0.03	0.04	0.01	0.553	0.928	1.567
14	0.022	0.037	0.059	-0.09	0.552	0.939	1.587
9	0.034	0.033	0.048	0.535	0.64	0.998	1.719
47	0.057	0.038	0.057	-0.577	0.601	1.084	1.78
15	0.055	0.041	0.062	-0.518	0.614	1.097	1.814
13	0.087	0.039	0.054	-0.216	0.624	1.076	1.826
19	0.271	0.047	0.04	0.64	0.598	0.934	1.85
45	0.092	0.044	0.064	-0.418	0.627	1.104	1.867
10	0.033	0.033	0.051	-0.072	0.662	1.123	1.869
36	0.18	0.04	0.04	-0.024	0.631	1.065	1.908
32	0.028	0.036	0.058	-0.467	0.673	1.19	1.957
30	0.46	0.05	0.04	-0.827	0.502	0.956	1.971
11	0.241	0.043	0.039	-0.201	0.646	1.109	2.039
41	0.318	0.05	0.057	1.034	0.657	0.98	2.059
17	0.145	0.042	0.055	0.057	0.723	1.21	2.12
18	0.302	0.054	0.061	0.715	0.693	1.081	2.13
27	0.59	0.06	0.05	0.34	0.574	0.923	2.149
29	0.5	0.06	0.04	0.367	0.627	1.012	2.191
8	0.035	0.027	0.039	0.165	0.809	1.339	2.214
5	0.408	0.048	0.035	-0.393	0.658	1.153	2.267
42	0.163	0.043	0.055	0.657	0.805	1.28	2.291
26	0.43	0.05	0.04	0.319	0.706	1.15	2.333
37	0.594	0.06	0.038	0.159	0.678	1.121	2.453
39	0.623	0.062	0.054	0.148	0.763	1.264	2.712

Table 3. Continued

Facility ID#	Ra-226 (pCi/L)			Ra-228 (pCi/L)			Total Combined Radium[3] (pCi/L)
	Result	Uncertainty	MDA[1]	Result[2]	Uncertainty	MDA	
7	1.17	0.08	0.04	0.631	0.582	0.9	2.728
21	0.45	0.06	0.04	1.505	0.805	1.177	2.814
22	0.688	0.059	0.038	0.03	0.78	1.307	2.834
23	1.133	0.08	0.056	0.575	0.69	1.095	2.998
43	1.23	0.079	0.03	1.038	0.693	1.049	3.051
40	0.999	0.072	0.029	1.104	0.802	1.214	3.087
46	1.465	0.092	0.044	0.603	0.607	0.947	3.111
49	1.552	0.093	0.039	0.362	0.625	1.006	3.276
44	1.792	0.095	0.036	0.661	0.616	0.961	3.464
1	1.592	0.093	0.053	1.28	0.766	1.142	3.73
3	2.343	0.12	0.065	0.788	0.695	1.076	4.234
35	3.45	0.142	0.04	0.23	0.66	1.09	5.346
34	3.79	0.146	0.034	-0.18	0.61	1.04	5.581
31	3.81	0.15	0.04	0.739	0.713	1.107	5.779
20	1.399	0.088	0.055	3.878	0.768	0.908	6.133
4	3.47	0.14	0.04	2.71	0.78	0.63	7.099
48	4.62	0.17	0.04	2.46	0.78	0.62	8.025
16	2.35	0.11	0.05	5.594	0.864	0.937	8.916
28	29.256	0.357	0.038	1.197	0.811	1.225	31.649
28	18.927	0.298	0.038	17.891	1.315	0.93	38.431
25	8.308	0.21	0.041	29.221	1.782	1.094	39.521
2	23.21	0.32	0.039	15.751	1.476	1.186	40.757
24	19.246	0.304	0.048	85.046	2.738	0.969	107.334
24	26.636	0.377	0.041	92.321	3.397	1.356	122.731

[1] Minimum detectable amount.
[2] In radiochemistry analysis, a negative sample result can occur when a sample has little radioactivity, and the analytical results show a normal distribution of positive and negative values around zero. This can happen when a sample value is less than that of the system's background.
[3] Total combined radium is conservative value that adds the result or MDA for Ra-226 and Ra-228 (whichever is greater) and their respective uncertainty values.

IV. Conclusions

Throughout the study and ongoing evaluation of the data, DEP did not identify any levels of radiation associated with the landfill radium leachate investigation that raised concern for environmental protection or public health and safety. No results were observed that would require landfill action or suggest changes to engineering or operational controls.

While the radiochemistry results indicate that there is currently no concern with the levels of combined radium in untreated leachate, and therefore, based upon the NRC developed limits, no current cause for concern with the levels of combined radium contained in discharges from subsequent treatment, the data set on which this determination is made is limited. It is important to recognize that more landfill leachate samples and radiochemistry analysis is warranted to generate additional data to confirm these initial findings.

DEP recommends at least 4 more quarters worth of radiochemistry analysis of untreated landfill leachate at all 49 landfills to generate additional results that provide a larger data set with the level of accuracy and certainty needed to more fully assess the levels of combined radium in landfill leachate and the levels of combined radium between landfills that do or do not accept oil and gas waste for disposal. The additional data will serve to inform future decisions to revisit landfill leachate sampling requirements, TENORM disposal protocols and other operational or engineering controls that may prove necessary to protect public health, safety and the environment.

References

(1) **Radionuclide Basics: Radium** (Last updated on February 6, 2025) U.S. EPA. https://www.epa.gov/radiation/radionuclide-basics-radium

(2) **Appendix B to Part 20—Annual Limits on Intake (ALIs) and Derived Air Concentrations (DACs) of Radionuclides for Occupational Exposure; Effluent Concentrations; Concentrations for Release to Sewerage** (Last updated on Wednesday, July 21, 2021) U.S.NRC. https://www.nrc.gov/reading-rm/doc-collections/cfr/part020/part020-appb