CoPhysics CORPORATION

Report: A Review of Drill Cuttings Disposal at the Hakes C&D Landfill and Response to Public Comments

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Introduction

This report presents radioactivity issues associated with the Hakes C&D Landfill (Hakes Landfill or Landfill) and has been prepared by CoPhysics Corporation (CoPhysics) for Casella Waste Systems (Casella). Information concerning landfill construction has been provided by Casella, legal references by counsel, and oil/gas technical information by various engineering consultants. This report presents a brief discussion of oil/gas drilling technology, a history of oil/gas waste disposal, and responses to comments from the public regarding radioactivity issues associated with the disposal of drill cuttings in the Hakes Landfill.

PART I

PERTINENT BACKGROUND INFORMATION

A. DRILLING WASTE: WHAT IS, AND IS NOT, ALLOWABLE IN PART 360 LANDFILLS

a. Background

Drilling operations have been conducted in New York and Pennsylvania since the late 1800s. Approximately 14,000 wells are still active in New York,[1] and new wells are drilled each year. Thus, oil and gas drilling waste is not a new waste. The main difference between the historical oil and gas waste and the new waste coming into New York from Pennsylvania is that the recent wells are drilled not only vertically, but also horizontally, therefore, producing more tons of rock chips and/or "cuttings" per well, due to the increased total length of the boring. The technique of hydraulic fracturing, or "fracking," is a method involving the injection of pressurized water into the bore hole which is used to create cracks in the rock to allow the oil and gas to migrate into the well. Therefore, the waste waters from this process are also produced in larger volumes than with conventional vertical wells. The oil and gas exploration companies have developed many special techniques to handle these wastes.

b. The Types of Waste Resulting from Oil and Gas Drilling Operations

Oil and gas drilling operations produce a variety of wastes which have very different characteristics and, therefore, their management and disposal are governed by distinct regulatory requirements. As described below, the types of waste produced from oil and gas drilling include

[1] NYSDEC. http://www.dec.ny.gov/energy/205.html

drill cuttings, produced water (or production brine), flowback water, scale, sludge, used frack sand, filter cake, and discarded equipment.[2]

Drill Cuttings: Drill cuttings are pulverized rock chips created by a drilling rig as it rotates and pushes a drill bit through many layers of rock, going down as far as two miles below the ground surface, then gradually turning and travelling horizontally through an extended distance in the gas-containing rock layer. Drill cuttings are often misrepresented as "fracking waste." They have nothing to do with hydraulic fracturing, but are merely rock chips and/or dust brought to the surface with some type of cooling and lubricating fluid termed "drilling mud." The cooling fluid is generally compressed air, a water-based mud, or an oil-based mud. The oil-based fluids used to lubricate the drill bit generally utilize a synthetic, food-quality oil.

To transport and dispose of the cuttings and mud, a bulking agent, such as sawdust, cement kiln dust, or lime, is often mixed in to thicken the mixture and to reduce free liquids. Mixing occurs at the drill site or at the landfill. The free liquids that may be in the rock dust are either residual drilling mud or deep groundwater.

Drill cuttings can contain slightly elevated concentrations of naturally occurring radioactive material (NORM), depending on which rock layer is being drilled. The main gas-producing layer of rock currently being drilled in Pennsylvania is the Marcellus shale, which in Pennsylvania occurs at depths of 5,000 to 10,000 feet. As the Marcellus shale formation extends up into New York, it slopes upward so that it surfaces at ground level in the vicinity of Syracuse, New York. Marcellus shale contains slightly more radioactive minerals than normal soil, clay or rock and has about the same concentration of radioactivity as red brick and granite counter tops. However, it contains less radioactive minerals than does gypsum, refractory (yellow) brick, and fertilizer. (The land area near Syracuse where the Marcellus shale is at the surface is not particularly radioactive.)

Sludge – Sludge from oil and gas drilling rigs accumulates at the bottom of fluid holding tanks. Sludge containing NORM from oil and gas operations is *not* disposed in New York landfills operating with Part 360 permits because the NORM is considered to be concentrated via settling to the bottom of the tank, resulting in higher levels of minerals,

[2] Another waste that can result during oil and gas operations, although it is unrelated to the drilling process, is spill cleanup waste. Spill cleanup waste originates from typical industrial spills unrelated to the actual drilling process, such as spills of hydraulic fluid or diesel fuel, and this waste may also contain soil, sand, vermiculite and absorbent cotton pads. Additional soil or other bulking agents are added to the spill waste to absorb the fluids to allow for transport and disposal.

some of which contain NORM. Therefore, this concentrated NORM in sludge is subject to regulation as a radioactive waste under 6 NYCRR Part 380. Ordinary sewage treatment plants can also generate sludge as a result of the sewage treatment process, which can be disposed of in a landfill, so long as it does not contain concentrated levels of radioactivity.

Used Frack Sand – During the hydraulic fracturing process, sand is injected into oil and gas wells so that it can travel into the cracks in the rock surrounding the horizontal portion of the hole. The sand particles, termed a proppant, act as wedges to keep the cracks from resealing so the oil and gas can flow from the rock formation into the well. The sand that does not get lodged in cracks is flushed back out of the hole and becomes a waste product. This waste material usually is flushed out with flowback water.

Flowback Water – Flowback water is the portion of water that is returned to the surface after being injected into a well during the hydraulic fracturing process. This waste is not a solid waste and is *not* accepted at Part 360 landfills; rather, it must be treated at the drilling site or at a nearby filtration or recycling plant. 6 NYCRR 363-7.1(o)(9) prohibits the disposal of fluids from oil and gas production wells, including flowback water and production brine, in Part 360 facilities.

Scale - As brine, oil, and/or gas proceed from underground to the surface, pressure and temperature change and certain dissolved salts can precipitate and adhere to the borehole interior as well as to ancillary piping in the rig facility as scale. Because scale is calcium-based and radium is chemically similar to calcium, radium concentrations in scale are normally high and, thus, scale is *not* accepted for disposal at Part 360 landfills.

Produced Water/Production Brine – Produced water is water that comes out of the rock formation during the lifetime of an oil or gas well. This waste is *not* accepted at Part 360 landfills because it is not a solid waste and is not approved for solidification. 6 NYCRR 363-7.1(o)(9) prohibits the disposal of fluids from oil and gas production wells, including flowback water and production brine, in Part 360 facilities. Produced water/production brine must be treated at a filtration or recycling plant.

Filter Cake – Flowback water, production water or brine may be filtered or evaporated as part of the water treatment process, thus creating filter cakes and evaporator bottoms. Because such a process concentrates NORM, filter cakes and evaporator bottoms are *not* permitted in New York Part landfills.

As noted above, fluids from an oil or gas production well, including flowback water and production brine, are prohibited in Part 360 facilities because they are not solid wastes. Also prohibited are any wastes where the NORM has been processed and concentrated (such as scale,

sludge, and filter cake). 6 NYCRR 380-1.2(e) & 380-2.1(a)(66). Thus, these types of wastes are *not* accepted at any of Casella's New York landfills. The wastes that contain processed or concentrated levels of radioactivity above background qualify as a regulated radioactive waste (which is prohibited in Part 360 MSW or C&D landfills). In marked contrast, drill cuttings contain relatively low levels of NORM similar to red bricks and granite (because there has been no processing or other activity that concentrates the NORM); thus, drill cuttings are not regulated as radioactive waste and are allowed to be disposed in Part 360 landfills as part of the industrial waste stream or as construction waste.[3] That is, oil-based drill cuttings are allowed in MSW landfills as industrial waste and water- and air- based drill cuttings are allowed in C&D landfills as construction waste. These issues, including the distinction between NORM and "technologically enhanced naturally occurring radioactive material" (TENORM), are more fully discussed below.

c. NORM and TENORM

NORM is "naturally occurring radioactive material" that occurs in rock, clay, sand, soil, groundwater, or other natural materials. The principal radionuclide of concern in NORM is radium-226, which is present in soil in concentrations of about 1 pico Curie per gram (pCi/g).[4] Some types of NORM may have radium-226 concentrations that are much higher than 1 pCi/g, and may be as high as hundreds or thousands of pCi/g in different types of naturally occurring salts and ores. Such natural, non-concentrated materials are accepted at New York landfills, however, *only* if the concentration of radium does not exceed 25 pCi/g. 6 NYCRR 363-7.1(o)(8).

TENORM is "technologically enhanced naturally occurring radioactive material," which is NORM that has been modified by an industrial process that causes the radioactivity in the NORM to be concentrated (intentionally or unintentionally).[5] Some industrial processes cause concentration of radioactivity during the extraction of minerals from rock via melting or chemical digestion. Filtration or evaporation of water also concentrates NORM into TENORM as sludge, scale, salt or filter cake. TENORM is not produced by merely chopping or drilling rock or baking clay into ceramic, because the concentration or enhancement of radioactivity does not occur to any significant degree. TENORM is *not* accepted at New York landfills whether its radium concentration is less than, equal to, or greater than 25 pCi/g. 6 NYCRR 363-7.1(o)(7).

The distinction between NORM and TENORM, including as these terms pertain to wastes from oil and gas drilling, is also explicitly set forth in amended 6 NYCRR Part 380 (effective

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[3] Also in contrast to New York regulation, Pennsylvania landfills accept some of these other drilling wastes, which may explain more frequent positive detections of radioactivity at those landfills.

[4] U.S. Environmental Protection Agency (EPA), "About TENORM." http://www.epa.gov/radiation/tenorm/about.html

[5] Ohio Department of Health NORM/TENORM Fact Sheet.

May 10, 2018), which regulates radioactive waste disposal. Consistent with the predecessor regulations, "processed and concentrated" NORM is regulated as a radioactive waste under Part 380. 6 NYCRR 380-1.2(e). As pertinent here, the recent amendments to Part 380 simply clarify that processed and concentrated NORM is the same thing as TENORM. And, because TENORM is regulated as a radioactive material under Part 380, it is not allowed to be disposed in Part 360/363 landfills.

As for oil/gas industry wastes, in responses to public comment received on the proposed amendments to Part 380, the NYSDEC addressed the difference between drill cuttings versus completion/production wastes (such as flowback water, production brine, and wastes resulting from treatment of these fluids). NYSDEC, *Assessment of Public Comment – Comments Received on Proposed Amendments to 6 NYCRR 380* (April 10, 2018) (Part 380 Public Comment Assessment), Responses 1-1, 4-1, 65-4(c). In those responses, the NYSDEC rejected the contention that all waste from the oil and gas industry should be classified as TENORM, stating: (1) processed and concentrated NORM, i.e., TENORM, continues to be regulated under Part 380; (2) waste with NORM in "natural isotopic abundance" is not regulated under Part 380; (3) drill cuttings have NORM in natural isotopic abundance because there has been no processing or concentrating, and, therefore, "[i]t would be inappropriate to re-classify [this waste] as TENORM;" (4) drill cuttings may be disposed in Part 360/363 landfills so long as there are no elevated radioactivity levels (as determined by radiation detector monitoring); and (5) in contrast, completion and production wastes are prohibited from disposal in landfills per Part 363. As discussed below, these regulations (Parts 360, 363, 380), govern what is, and is not, allowable in Casella's New York landfills.

d. The Types of Drilling Waste Accepted at the Hakes Landfill and Other Casella New York Landfills

Casella operates three New York landfills that currently accept drilling waste (Hakes C&D, Chemung, and Hyland). The waste accepted is limited to drill cuttings and pad deconstruction waste such as gravel, fiber mats, dirt, synthetic liner material, and discarded equipment. In addition to drill cuttings, the Hyland Landfill accepts contaminated soils from typical industrial spill and cleanup waste, such as hydraulic oil leaks and diesel fuel spills. This is similar to the wastes that are accepted from other industrial operations and has nothing to do with actual drilling operations.

The Hakes Landfill, being a C&D debris landfill, accepts only air- and water- based drill cuttings and drill pad demolition waste.[6] Any other oil and gas drilling wastes would be

[6] This is confirmed in, among other documents, the e-mail from G. Maslanka, NYSDEC, to J. Boyles, dated Jan. 21, 2010 (**Exhibit A**), which states: "cutting[s] from wells utilizing oil based cutting fluids may be disposed on in the **MSW landfill only.** Cutting[s] generated from wells using water based cutting fluids may be disposed of in the MSW or C&D landfill." The Chemung Landfill, being a MSW landfill, accepts air-based, water-based, and oil-based drill

accepted at Casella's other New York landfills only following compliance with the Part 360 permits approved for each facility, Casella's industrial waste acceptance protocol, and, where appropriate, approval from the NYSDEC.

It is also important to note that the waste types authorized for disposal at Casella's New York landfills are based on characteristics of the waste stream itself and are independent of the location at which the waste is produced. Casella's New York landfills do not accept any materials where radioactivity has been concentrated or enhanced due to processing, and this is so regardless of whether the waste originates from New York or Pennsylvania. In contrast, Pennsylvania landfills accept a much wider variety of oil and gas drilling waste. For example, Casella's New York landfills do not accept scale, sludge, filter cake, produced water, or flowback water; whereas Pennsylvania landfills accept scale and sludge (subject to acceptable radiation readings).

Consequently, any meaningful assessment of radiological risk associated with the Hakes Landfill (or other Casella New York landfills) must distinguish between the types of drilling wastes that are, and are not, authorized for disposal under New York's regulatory scheme (which is further discussed below). As a corollary, data sources cited by some of the commentators (such as studies conducted at Pennsylvania disposal facilities) do not provide meaningful comparisons to New York landfills, such as Hakes, Chemung and Hyland, which do not accept concentrated NORM waste types.

Finally, as is noted above, because the Hakes Landfill is a C&D landfill, it may only accept drilling wastes that are produced when drilling with air or water. Typically, this type of drilling is utilized for the vertical section of the well to a point below the water bearing zone and

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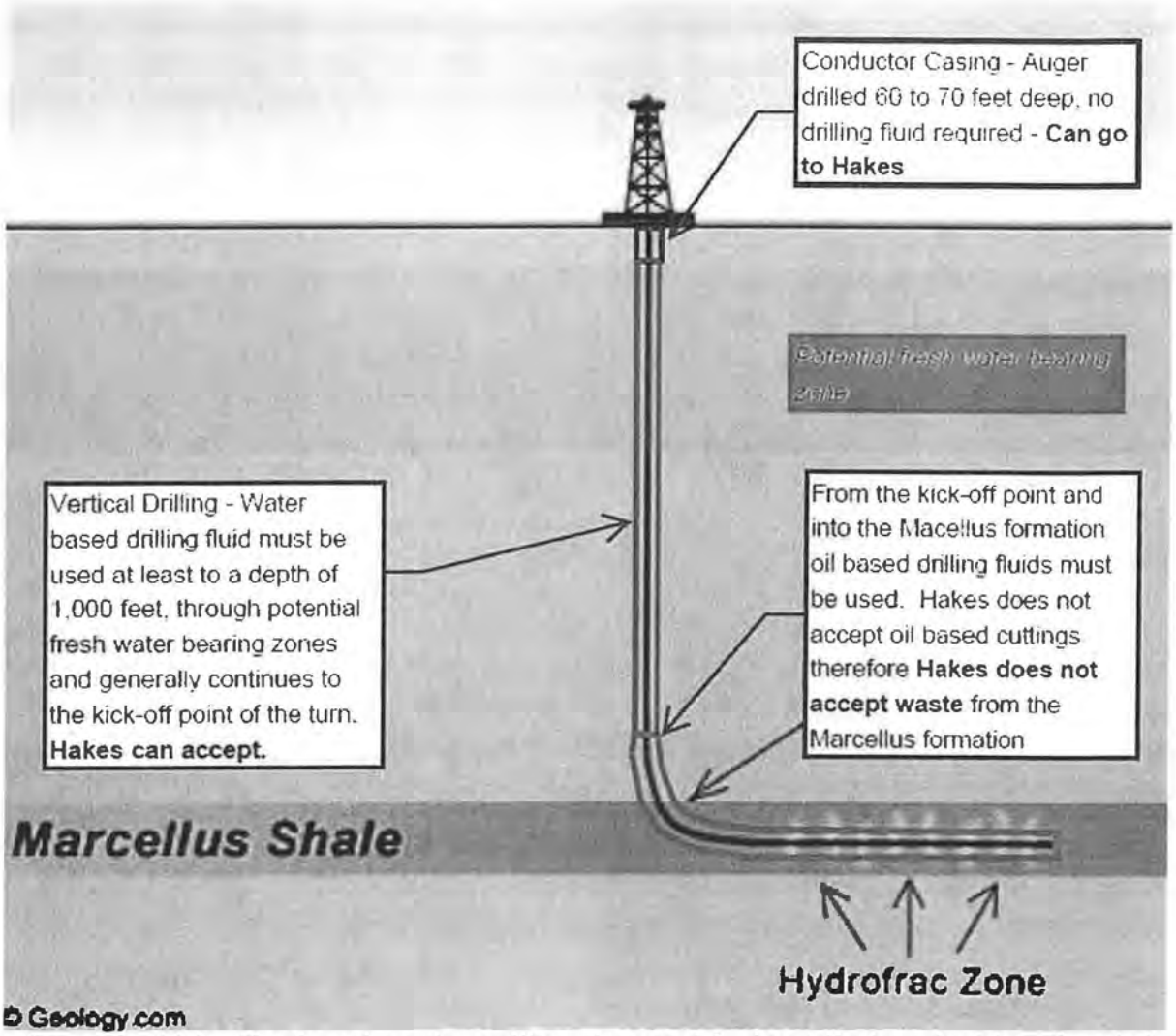
cuttings, oil-contaminated soils from industrial spills, and drill pad demolition waste; and this is noted in the administrative decision, *Matter of Application of Chemung County Landfill*, Decision of Commissioner (Aug. 4, 2011), 2011 WL 6934245, at *6. This decision references Department Staff's Jan. 21, 2010 e-mail and notes that in approving waste streams for disposal at the Chemung Landfill, Staff directed that "cuttings from wells utilizing oil-based cutting fluids may be disposed in the MSW landfill only, but cuttings generated from wells using water-based cutting fluids may be disposed in the MSW landfill or Chemung County's on-site C&D debris landfill." The different disposal requirements for oil- versus air- and water- based drill cuttings are also noted in the NYSDEC's May 2015 Final Supplemental Generic Environmental Impact Statement for Horizontal Drilling and High-Volume Hydraulic Fracturing to Develop the Marcellus Shale and Other Low-Permeability Gas Reservoirs (HVHF FSGEIS), §§ 5.2.4 (which states that, as described in section 5.13.1, the proper disposal method for drill cuttings is determined by the composition of the fluid or fluids used during drilling) & 5.13.1 (which states that [1] on-site burial at the well site of cuttings generated during compressed air drilling or drilling with fresh water as a drilling fluid is allowable; but [2] cuttings generated during drilling with polymer or oil-based muds are considered industrial non-hazardous waste and therefore must be removed from the site by a permitted Part 364 waste transporter and properly disposed in a solid waste landfill).



prior to the kick-off point where the wellbore is turned horizontally into the Marcellus shale formation. This means that the drill cuttings that are received at the Hakes Landfill are not from the Marcellus formation, which, as is noted above, is suspected of having slightly higher concentrations of radioactivity. Stated another way, the drill cuttings received at the Hakes Landfill are not from any formation suspected of higher radioactivity. The following diagram illustrates this concept.

B. HISTORICAL REGULATION OF CASELLA'S NEW YORK LANDFILLS

a. General Background

All landfills in New York are subject to regulations regarding the types of wastes that may be received. Disposal of solid waste (i.e., discarded material resulting from industrial,

municipal, commercial, institutional, mining, agricultural operations or residential activities) that does not qualify as "prohibited radioactive waste" is regulated differently from disposal of actual radioactive waste. 6 NYCRR Parts 360 & 363 (regulating solid waste disposal); 6 NYCRR Parts 380, 382 & 383 (regulating radioactive waste disposal); 6 NYCRR 360.2(b)(206) (defining prohibited radioactive material to mean radioactive material subject to Part 380).

Under New York's regulatory scheme, for NORM to be classified as prohibited radioactive waste (i.e., waste not acceptable in Part 360/363 solid waste landfills, such as Casella's New York landfills), the NORM would have to be processed and concentrated (making it TENORM) or would have to be NORM exceeding 25 pCi/g of radium. 6 NYCRR 382.1(c)(5); 6 NYCRR 360.1(a)(1)(ii); 6 NYCRR 380-1.2(e); 6 NYCRR 363-7.1(o)(8); Part 380 Public Comment Assessment, Responses 1-1, 4-1, 14-1, 15-4, 15-5, 15-6, 15-17, & 65-4(c). For example, sludges and filter cakes are the result of concentrating liquids and, therefore, qualify as regulated radioactive materials under Part 380 (which materials are not allowed in Casella's New York landfills). Drill cuttings, spill cleanup soils and pad de-construction materials, however, are not "processed and concentrated" and, therefore, are not prohibited/regulated radioactive wastes; rather, they are classified as industrial waste (if oil-based) or construction waste (if air- or water- based), and regulated under Part 360 (and Part 363).

b. Historical Regulation at the Chemung, Hakes and Hyland Landfills

As a general matter, the Department has procedures in place for landfills to gain approval to accept different waste types. Any industrial waste stream that is being considered for disposal at a New York landfill is tested in accordance with the facility's industrial waste acceptance protocol. The Department then has the ability to review the test results and either approve or reject the waste as being authorized for disposal at the landfill.

Relative to drilling waste, the first Casella landfill in New York to receive a specific approval to accept drilling waste was the Chemung Landfill. In 2009, working in cooperation with and under the oversight of the Department, Casella engaged in a study to determine both the short- and long- term risks associated with acceptance of Marcellus shale drill cuttings. As more fully described below, this impact study focused on evaluating the concentrations of radium-226, thorium-232 and potassium-40 in drill cuttings and modeling any potential long-term impacts of their disposal in landfills.

The Radioactivity Impact Study

To evaluate possible risks associated with acceptance of drill cuttings, the services of a hydrologist and a radioactivity consultant (CoPhysics) were engaged by Casella in 2010 to perform a risk assessment of a landfill being completely filled with 50 pCi/g of radium-bearing material (as a highly conservative starting point). Radium-226 is used as the main radionuclide of interest because it and its progeny cause the majority of the radiation dose to humans in the North American natural environment. While uranium-238 (and its immediate progeny),

thorium-232 (and progeny) and potassium-40 all exist in NORM, they account for a small fraction of the dose from exposure to NORM. Therefore, radium-226 and its progeny (radon-222, polonium-218, lead-214, bismuth-214, polonium-214, lead-210, bismuth-210 and polonium-210) are specifically assessed. They include both alpha and beta/gamma radiation emitters. (An interesting side-note: In Brazil, high thorium-232 concentrations in the natural environment cause elevated radiation doses to beach-goers there. Radiation assessments in Brazil therefore concentrate on thorium-232 rather than radium-226.)

The drill cuttings assessment for New York landfills used the RESRAD radiation dose modeling computer code, the industry standard for such analyses. The results of the assessment showed that a hypothetical future resident living on top of the landfill would not encounter any significant health risks due to the presence of underlying radium at 50 pCi/g.

The next step in the assessment was to determine what the actual concentrations of radium were in the drill cuttings to see if such concentrations were less than or greater than 50 pCi/g. For this step, Casella engaged the services of a geologist and radioactivity consultant (CoPhysics) to obtain and analyze representative samples of drill cuttings from the Marcellus shale formation in Pennsylvania, as well as samples from trucks arriving at the three New York landfills. Samples were collected from well sites during active drilling of the Marcellus shale.

The geologist inspected the samples and reviewed the boring logs to ensure that the samples were from the Marcellus shale formation. CoPhysics performed on-site radiation readings of piles of cuttings and collected samples for laboratory analysis. On-site readings using portable instrumentation at the drill sites and the landfills showed no detectable radiation levels greater than background (which is the general level of radioactivity existing in the surrounding environment).

In addition, drill cutting samples from the drilling sites (i.e., from the Marcellus shale formation) and from the landfills were collected for laboratory analysis. The samples were not dried before analysis but were analyzed by gamma spectroscopy in a wet, as-collected state to be most representative of the waste. The radium concentration in the cuttings ranged from 0.6 to 4.3 pCi/g, with an average of 2.1 pCi/g (+/- 1.2). This level is just slightly over background (which was found to be 0.9 pCi/g +/- 0.1 in local soil), is also comparable to radium levels in other commonly encountered construction and natural materials, and is well under USEPA cleanup limits for Superfund sites. CoPhysics Corp., *Radiological Survey Report Marcellus Shale Drilling Cuttings* (April 2010) (CoPhysics 2010 Report) (**Exhibit B**).[7]

[7] The results for potassium-40 and thorium-232 revealed that levels in Pennsylvania drill cuttings are lower than New York site background, again demonstrating no radiological risk. CoPhysics 2010 Report (**Exhibit B**), pp. 5 & 7 (Appendix A).

The following table presents the approximate radium concentrations found in various materials, which can be compared to the 5 pCi/g regulatory limit established by the USEPA for unrestricted use after radium cleanup (40 CFR 192). As shown by the following table, the radium concentrations detected in the drill cutting samples are lower than most of these commonly used materials and are also lower than the 5 pCi/g regulatory limit.

Typical Radium Levels* for Comparison

Material or Guideline	Approximate Radium Concentration (pCi/g)
Uranium ore	150 – 1000's
Mineral deposits at Saratoga Performing Arts Center	50 – 80
Yellow brick (fire brick)	4 – 80
Sand blast sand	2 – 20
Phospho-gypsum	10 – 30
Fertilizer	5 – 20
Kitty litter	3 -10
Granite Counter Tops	1 – 7
Marcellus Shale	1 – 4
Coal Ash	1 – 10
Red brick	1 – 2
Clay	1 – 3
General soil or rock	0.5 – 1
Topsoil	0.1 – 0.2

* Material concentration estimates were obtained from prior sampling projects by CoPhysics.

In summary, the extensive review and study regarding the acceptance of drill cuttings at Casella facilities showed that the drill cuttings contained very low levels of radioactivity (i.e., radium-226 just slightly above local background and less than USEPA cleanup guidelines for

unrestricted use) and would not pose a threat to public health, workers, or the environment. The NYSDEC comprehensively reviewed all of this material and fully evaluated the waste and any potential dangers. Based on the extensive review by the NYSDEC, drill cuttings were considered acceptable wastes at the three facilities in New York operated by Casella and several other municipal landfills in New York, with the notable caveat that only drill cuttings produced by drilling with air or water are allowed at the Hakes Landfill as construction waste (i.e., no oil permitted).

Moreover, these findings by the NYSDEC – that drill cuttings (in contrast to other oil and gas production wastes) are acceptable for disposal in Part 360 landfills and do not pose an environmental or public health threat – have been revisited and extensively reviewed on a number of occasions and consistently reconfirmed. Legal counsel has listed such confirmations as follows: the Department's (1) HVHF FSGEIS; (2) Responsiveness Summary relative to the Chemung County Landfill Expansion, dated July 29, 2016 (2016 Chemung Responsiveness Summary); and (3) new Part 360 and Part 363 regulations. HVHF FSGEIS, Vol. 1, §§ 1.7.10, 5.2.4.2, 5.13.1, 6.1.9.1, 6.7, 7.7.2 & Vol. 2, § 4, pp. RTC-100 – RTC-101 (**Exhibit C**); 2016 Chemung Responsiveness Summary, at pp. 31-59 (**Exhibit D**); 6 NYCRR Parts 360 & 363 (discussed below); *Matter of Chemung County,* 2011 WL 6934245, at *3 (Aug. 4, 2011).

Note, too, that the analyses included in the 2010 CoPhysics Report (**Exhibit B**) were performed with samples from the Marcellus shale formation, i.e., the shale formation of concern due to radium levels just slightly above background. The Hakes Landfill, however, is not authorized to accept cuttings from the Marcellus shale formation because those cuttings include oil-based drilling fluid, thus further demonstrating that drill cutting disposal at Hakes is not an environmental or public safety threat.

Monitoring Protocols at Casella's Landfills

Regarding the acceptance of drill cuttings, highly conservative acceptance criteria and state-of-the art monitoring procedures were developed and implemented at all three Casella landfills (Chemung, Hakes and Hyland).

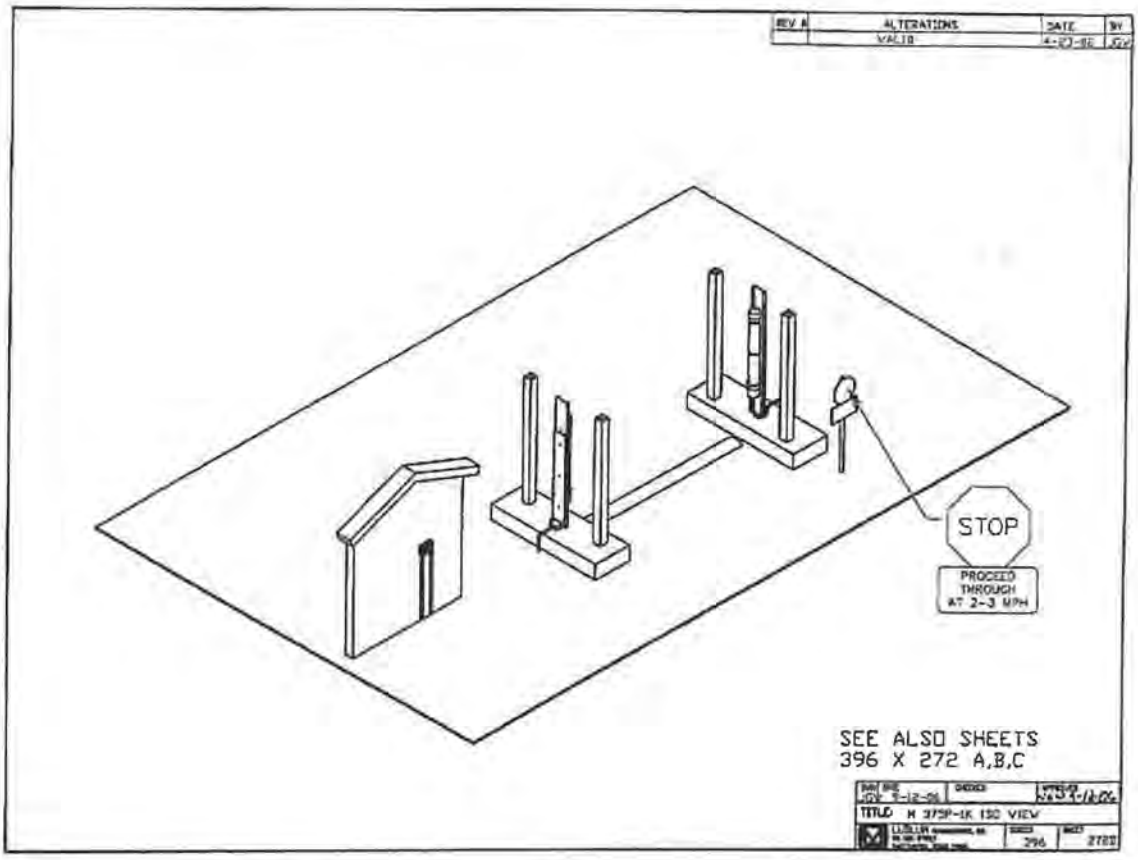
As to acceptance protocols, the initial radium limits for incoming waste were conservatively set at 25 pCi/g as an annual average and 50 pCi/g for any one truckload. These limits (which were applied at all three Casella landfills) were derived from the extensive radiation dose/risk analysis (discussed above) that assumed the landfill was filled to the permitted capacity with cuttings-type material containing 50 pCi/g of radium and a farmer built a home on the landfill and grew crops there. The results indicated that the resident would not receive a radiation dose in excess of prescribed limits. However, the NYSDEC wanted to add an additional safety factor for non-technical reasons and set the limit at 25 pCi/g as an annual average. (The acceptance of a single truckload up to 50 pCi/g was later eliminated by the NYSDEC, with the regulatory limit for incoming waste being set at 25 pCi/g).

As for monitoring protocols, to ensure that no processed and concentrated wastes were accepted and to ensure compliance with the established radiation limits, gamma radiation detectors were installed at Hyland, Hakes, and Chemung to monitor incoming waste loads for potential radioactivity. These detectors were added in 2010 to ensure that the three sites do not accept regulated radioactive waste; that is, the detectors were installed as a precautionary measure to protect public health and identify and preempt the disposal of potentially unacceptable wastes. The radiation alarms are calibrated to provide sufficient sensitivity to allow detection of unauthorized types of radioactive materials. The portal radiation detection system in operation at all three landfills was developed in coordination with, and was approved by, the NYSDEC. This system is similar to the many systems that are used throughout the solid waste industry to screen for wastes that contain radioactivity. In other words, these gamma radiation detectors are an accepted, widely used, state-of-the-art technology for screening incoming waste loads on trucks.

All vehicles entering any of the landfills must pass through the radiation detectors mounted at the truck-weighing scales or scale house. As the truck enters the scale and stops at the scale house, it proceeds slowly through the detectors, at which time, if an exceedance occurs, unauthorized levels of radioactivity would be detected and an alarm would sound. The radiation alarms at the landfill entrances are set to sound at approximately 15 pCi/g as an "investigation" level. This investigation level allows landfill personnel to check the contents of such a load to ensure that it does not contain any unauthorized industrial radiation source. If a load of waste causes the investigation alarm to be triggered, then the Operation & Maintenance Manual (now called the Facility Manual) requires a sequence of procedures to determine whether the source that triggered the alarm is the driver (possible nuclear medicine patient) or the waste material. If it is determined that the source is the waste material, the material is analyzed, and the NYSDEC and other agencies are notified to assist in determining the proper course of action for the waste. The results of the analysis determine if the load meets the regulatory limit.

The radiation detectors at each site are checked daily for proper operation using a small, radioactive check source, as well as a check of the natural background gamma radiation reading. The detectors also undergo a full calibration on an annual basis by a licensed third-party consultant. The NYSDEC performs one to two unannounced inspections of each landfill every week and has never found the detectors to be turned off or inoperable.

The radiation detectors were installed according to the manufacturer's specifications. A manufacturer's drawing is provided below. Note that the instructions on the sign that is posted at the entry to the radiation detectors require vehicles to stop and then proceed slowly through the detectors.



Casella's three landfills in New York continue this monitoring protocol to ensure that no waste exceeds the established limits for radioactivity. This protocol is also included in the Facility Manual for each landfill, compliance with which is required under the permits governing these facilities.

In addition, as noted above, the landfills use a NYSDEC-approved protocol for reporting all incidents of radiation alarm events. In the event that a load does trigger the alarm, a thorough examination of the truck is conducted and State and local officials are notified, including the police. Steps are taken to identify the type and strength of radioactivity, and the Department then determines the proper course of action for managing the material.

The use of these protocols at Casella's and other New York, New Jersey and Pennsylvania landfills has been successfully demonstrated over the past 20 years in detecting and investigating many incidents of unknown radiation sources, including nuclear medicine sources, radium and thorium in ceramics, improperly handled industrial sources of radioactivity, NORM in sand-blast sands, radium-contaminated soil, radium in building material (C&D) waste from 1920's era dial painting facilities, etc. We also know that this type of monitor easily detects filter cake because the system at the McKean County Pennsylvania filtration plant alarms when

filter cake is shipped for disposal at a radioactive material disposal site. The truck monitoring technique is highly proven and reliable.

And, this is so, even though the system detects gamma radiation only. In this regard, a note about commentators' criticisms is warranted. For the past 5 years, numerous commentators have criticized gamma radiation detection systems for their inability to detect alpha and beta radiation, thinking that alpha- or beta-emitting radionuclides could get into the landfill undetected. These commentators fail to realize that naturally occurring radioactivity consists of all three types of emitters: alpha, beta and gamma. NORM consists of some combination of the uranium-238 / radium-226 decay series and the thorium-232 decay series, both of which emit alpha, beta and gamma radiation in abundance. If there are alpha- and beta- emitting radionuclides, then there are also gamma emissions. Even the third constituent of NORM, potassium-40 is a beta-emitter, but it, too, emits a strong gamma ray along with its beta emission. NORM in soil or rock never exists in a form that does not emit gamma radiation. Only with extremely involved and expensive purification can the alpha emitters in the decay series be separated from the gamma emitters. Such purification does not occur with rock drilling. Therefore, gamma detection is and remains a proven, reliable means for accurately detecting NORM.

C. FORMALIZATION OF PROTOCOLS IN DEPARTMENT PROGRAM POLICY; EFFECTIVENESS OF GAMMA RADIATION DETECTION SYSTEM

In September 2015, the Department officially incorporated the regulatory radium concentration limits and monitoring protocols into a Program Policy. Letter from R. Phaneuf, Acting Director, Div. of Materials Mgt., NYSDEC, to J. Leone, Hakes C&D Debris Landfill, dated Sept. 18, 2015 (**Exhibit E**).

As to effectiveness of the radiation detectors, in addition to daily detector quality assurance tests, Casella records show direct proof that the monitors work. A review of the records of all three landfills shows that the alarms have sounded a total of six times since their installation in 2010. All six incidents were caused by wastes from nuclear medicine patients in trucks containing ordinary MSW or from medical treatment received by drivers. In the driver incidents, the truck drivers had undergone diagnostic medical procedures the day before coming to the landfill. The small amount of gamma radiation emitted by their bodies set off the landfill radiation alarm, thus demonstrating the sensitivity of the radiation detectors.

As to the underlying premise that drill cuttings contain low levels of radioactivity, further review of Casella records shows that since January 1, 2011, more than 500,000 tons of waste from the oil and gas industry have been accepted collectively at the Hakes, Hyland and Chemung Landfills. None of these waste loads have triggered the alarms. This fact (1) is consistent with the findings in initial radioactivity studies that there are low radium levels in drill cuttings (i.e., at

worst, just slightly above background); and (2) further demonstrates that the industry has been effective in keeping unauthorized drilling wastes (e.g., sludges, scales, etc.) out of their drill cutting trucks.

Leachate monitoring redundantly confirms that drill cuttings (including drill cuttings from Marcellus shale at Hyland and Chemung) do not result in significant radium levels in leachate and disposal of these materials in Part 360 landfills does not create any public health risk. Each of Casella's New York landfills is constructed to meet NYSDEC and USEPA standards to collect and manage leachate, which is the liquid passing through the waste contained within the landfill.

Regarding engineering features at the Hakes Landfill, the following information has been provided by Casella. The Hakes Landfill is constructed with a groundwater collection system, as well as a leachate collection system. The leachate collection system is designed to prevent leachate from escaping and contaminating groundwater or surface water. The volume of liquid accumulated in the leachate collection system is monitored daily, and the liquid from the leachate collection system is sampled and analyzed for radioactivity semi-annually. In addition, the groundwater collection system is sampled and analyzed every quarter, as are the groundwater monitoring wells that are spaced along the perimeter of the Landfill. To date, the collection systems at all three landfills are performing in accordance with the NYSDEC Part 360 regulations, which ensures that radioactivity in leachate is kept within environmentally safe levels.

More specifically, on-going leachate monitoring demonstrates that levels of radioactivity in the leachate remain far below allowable Part 380 discharge limits (i.e., be it as effluent discharge or sewer discharge). For example, at Chemung, leachate sampling results for radium-226 and radium-228, the radioactive isotopes most commonly linked to Marcellus shale drill cuttings, have ranged from non-detectable to 9.43 pCi/liter (pCi/L). The average radium concentration in Chemung leachate from 2012 to 2017 was 3.4 pCi/L. These levels are well within the NYSDEC approved Part 380 discharge limit of 600 pCi/L for discharges to a sewer system and 60 pCi/L for effluent discharges. 6 NYCRR 380-11.7 (Tables II & III).[8] All of the leachate analysis results have been within the normal range of radium concentrations in natural New York State groundwater. Actually, the average radium level in Chemung leachate is even

[8] As for decay products of radium-226, Part 380-11.7 provides no limit for radon-222 in effluent discharge or sewer discharge. Limits for bismuth-214 are 300,000 pCi/L (effluent) and 3,000,000 pCi/L (sewer). Limits for lead-214 are 100,000 pCi/L (effluent) and 1,000,000 pCi/L (sewer). Note that these limits apply to licensed radioactive materials facilities, but do not apply to Casella's New York Part 360 landfills. 6 NYCRR 380-1.2 (Part 380 applies to licensed radioactive materials and TENORM); Part 380 Public Comment Assessment, Response 15-17. The Department, however, has used these values as a guide in its review of radioactivity levels in leachate from Part 360 facilities to determine if sending the leachate to waste water treatment facilities is sufficiently protective.

less than the USEPA drinking water standard of 5 pCi/L even though such a comparison is not at issue (since leachate is not drinking water).

Additionally, the NYSDEC has repeatedly recognized in other proceedings that landfill leachate contains very low levels of radium, with no increasing trend. **Exhibit D** (pages 32-35, 37-38, 42, 44, 55-56, & 58 from the 2016 Chemung Responsiveness Summary, responding to at least 13 separate questions/comments alleging that radium in leachate from the Chemung landfill is increasing and poses environmental and health risks and rejecting same[9]). Thus, the NYSDEC has asserted that "[t]he Department has reviewed leachate data and has not observed an upward trend ... as alleged by the commentator ... Because the leachate values do not indicate increasing trends, and are one to two orders of magnitude lower than Part 380 discharge standards, it is considered protective of water quality to send the leachate to the WWTF." **Exhibit D** (Response #R4); **Exhibit D** (Response #RMR4, which states that the levels of radium from drill cuttings are close to or slightly higher than background and that leachate levels are one to two orders of magnitude lower than Part 380 discharge standards which were developed to be protective of biota).

In short, the sampling data from all three facilities, as reviewed and analyzed by the Department, confirm that there has been no discernible impact from drill cutting disposal over the past years – that is, radium concentrations are low and without any type of increasing trend.[10] **Exhibit F** (2012-2017 data from Hakes, Chemung and Hyland, showing radium-226 and radium-228 levels in leachate); **Exhibit G** (2018 sampling data for Hakes, showing levels of, among other radionuclides, radium-226 and radium-228 in leachate); **Exhibit D** (excerpts from 2016 Chemung Responsiveness Summary, discussed above). Note: Recent questions have been raised about radon concentrations in Hakes leachate, as opposed to radium. These issues are addressed in Part II of this report.

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[9] The specific questions/responses are #R3, #R4, #R7, #R10, #R11, #RMR1, #RMR3, #RMR4, #RP10, #RP16, #D6, #D7, and #D14. Health-related and environmental concerns are further addressed in **Exhibit D** in responses #H1-#H6 (which are pp. 62-64 of the 2016 Chemung Responsiveness Summary).

[10] Casella has indicated that leachate samples will continue to be collected to monitor levels of radioactivity at Casella's New York landfills. In addition, the leachate management facilities will continue to be cleaned and inspected annually, as required by the facilities' respective Facility Manuals. Casella has indicated that any sludge or sediment removed from the leachate storage lagoons will continue to be sampled, with samples sent to an approved laboratory for analysis, to verify that the sludge is appropriate for disposal within the landfill.

D. FINAL REGULATIONS/STANDARDS

Ultimately, the Department issued: (1) revised landfill regulations, effective November 5, 2017, formally adopting monitoring protocols for Part 360 landfills accepting drilling waste. 6 NYCRR 363-7.1(a)(5); and (2) amended Part 380 regulations, effective May 10, 2018, clarifying that TENORM is NORM that has been "processed and concentrated" and is subject to regulation as a radioactive waste under Part 380.

In addition to formalizing the monitoring protocols and clarifying the definition of TENORM, the revised regulations reconfirm that:

- NORM is not a regulated radioactive waste (unless it has been processed and concentrated) and, thus, is allowable in Part 360 landfills, 6 NYCRR 382.1(c)(5), 380-1.2(e), 360.2(b)(206), 360.1(a)(1)(ii);
- NORM that has been processed and concentrated (i.e., TENORM) is a regulated radioactive waste (subject to regulation under Part 380) and is prohibited from disposal in Part 360 landfills, 6 NYCRR 363-7.1(o)(7), 6 NYCRR 380-1.2(e); 6 NYCRR 380-1.2(a)(66);
- Wastes allowable in Part 360 facilities can have no free liquid and must contain a minimum of 20% solids, 6 NYCRR 363-7.1(i);
- Wastes exhibiting a concentration of greater than 25 pCi/g of radium-226 are prohibited in Part 360 landfills, 6 NYCRR 363-7.1(o)(8);
- Fluids produced from oil and gas production wells, including flowback liquid and production brine, are prohibited from disposal in Part 360 landfills, 6 NYCRR 363-7.1(o)(9);
- Industrial waste or drilling and production waste, if accepted, must be included in the landfill's waste control plan, 6 NYCRR 363-7.1(p); and
- Leachate will continue to be sampled, monitored and managed in accordance with regulatory requirements and the facility's approved environmental monitoring plan, 6 NYCRR 363-7.1(f)(4) & (g), 6 NYCRR 363-4.6(f)(8)(iii); and
- Regarding radon, except as a decay product of source or special nuclear material (which is not at issue here), radon is NORM, and any resulting radiation is a component of background radiation which is not subject to regulation under Part 380. 6 NYCRR 380-1.2(c) & (e); 6 NYCRR 380-2.1(a)(8).

PART II

RESPONSE TO PUBLIC COMMENTS

Part II of this report identifies and responds to key issues repeatedly raised in public comments.

KEY ISSUES

KEY ISSUE #1: Concerns Regarding the Type of Oil & Gas Drilling Waste Being Accepted at Hakes; Concerns about High Levels of Radioactivity Being Associated with "Fracking" Waste from Pennsylvania.

Commentators assert that, based on reports from the Pennsylvania Department of Environmental Protection (PADEP), significant levels of radioactivity are associated with "shale gas drilling wastes" such as produced water/production brine, storage equipment, flowback water, filter cake, scale and sludge. In other words, commentators believe that this "fracking waste" has high levels of radioactivity and claim that acceptance of this waste at the Hakes Landfill creates a radiological risk.

As a separate matter, commentators assert that there is significant radioactivity associated with drill cuttings and de-watered muds coming from fracking sites in Pennsylvania, and this is due to the drill cuttings being from the Marcellus shale formation. Commentators assert that, due to acceptance of these drill cuttings/muds from the Marcellus shale, there are high levels of radioactivity at the Hakes Landfill and, hence, a corresponding radiological risk.

RESPONSE TO KEY ISSUE #1:

Commentators' concerns regarding acceptance of "fracking waste" in Part 360 landfills reflect a misunderstanding of the types of waste that are, and are not, accepted at the Hakes Landfill and, for some of the wastes, at any other New York Part 360 landfill. As fully explained in Part I of this report, "fracking waste" (for example, flowback water, production waters/brine, sludge, pipe scale, filter cake, etc.) is not authorized for acceptance at any New York Part 360 landfill, including the Hakes Landfill. This is so because these wastes are either not "solid waste" or are the result of processing that concentrates NORM into TENORM. A discussion of this issue and related issues is contained in Part I of this report. Solid waste containing NORM that is not processed and concentrated is allowed in Part 360 facilities (provided it does not exceed 25 pCi/g of radium-226); TENORM is not allowed in Part 360 facilities, and this is so even if it contains less than 25 pCi/g of radium-226. The "fracking wastes" cited by the commentators are either not solid wastes or qualify as TENORM. Because these waste types have never been, and are not, authorized for acceptance at Hakes (or any New York Part 360

landfill), the commentators' concerns in this regard are not pertinent to the Hakes Landfill (or any other Part 360 facility).

As also explained in Part I of this report, drill cuttings and associated muds (which are the cooling/lubricating fluids used during drilling) are not "fracking waste;" rather, drill cuttings are pulverized rock chips that result from the drilling process. These "cuttings" and associated "muds," however, have nothing to do with the "fracking" process, which is a completion technique that injects pressurized water and a proppant (e.g., sand) into the bore hole to open cracks to allow gas or oil to flow to the well. Therefore, to the extent commentators' concerns are premised on either the acceptance of "fracking waste" at Hakes or the characterization of drill cuttings as "fracking waste," these concerns are unfounded because the Hakes Landfill does *not* accept fracking waste; nor does any Part 360 landfill in New York State.

Additionally, because New York Part 360 landfills (including Hakes) do *not* accept "fracking waste," commentators' concerns that are premised on reports from the PADEP relative to radiological issues at Pennsylvania landfills are equally unfounded. Pennsylvania landfills accept a broader array of oil and gas drilling wastes than do New York landfills, including some fracking wastes. New York landfills do *not* accept these waste types. Therefore, parallels cannot be drawn between Pennsylvania reports (or Pennsylvania landfills) and New York solid waste management facilities.

Finally, while some commentators acknowledge the distinction between drill cuttings/muds versus fracking waste, they assert (albeit incorrectly) that there is a radiological risk associated with Hakes accepting drill cuttings/muds because these materials come from the Marcellus shale formation which is associated with having slightly higher radioactivity (i.e., radium-226) than natural background levels. Here, too, the commentators confuse the nature of the waste that is, and is not, authorized for acceptance at Hakes.

As explained in Part I of this report, Hakes does not accept drill cuttings from the Marcellus formation because of the drill bit coolant used. Hakes is a C&D landfill, and, as such, may accept only cuttings that have been drilled with air- or water- based drilling fluids. This is reflected in the e-mail from G. Maslanka, NYSDEC, to J. Boyles, dated Jan. 21, 2010 (**Exhibit A**), which states: "cutting[s] from wells utilizing oil based cutting fluids may be disposed of in the **MSW landfill only.** Cutting[s] generated from wells using water based cutting fluids may be disposed of in the MSW or C&D landfill." This same fact is also noted in (1) *Matter of Application of Chemung County Landfill*, Decision of Commissioner (Aug. 4, 2011), 2011 WL 6934245, at *6 (which states that "cuttings from wells utilizing oil-based cutting fluids may be disposed in the MSW landfill only, but cuttings generated from wells using water-based cutting fluids may be disposed in the MSW landfill or Chemung County's on-site C&D debris landfill); and (2) HVHF FSGEIS, §§ 5.2.4 & 5.13.1 (**Exhibit C**). Drilling into the Marcellus formation, however, utilizes oil-based drilling fluids. While air- or water-based fluids are used on the vertical portion of the well-bore proceeding through the water-bearing zones, Casella has

confirmed with drillers that, after the kick off point, where the well-bore turns horizontally to drill into the Marcellus formation, oil-based fluids are used because of the greater friction at that stage of the drilling process.

Because Hakes is authorized to accept only air- and water- based drill cuttings, Hakes does not accept material containing rock fragments from the Marcellus shale formation. While certain commentators have noted various logs indicating that Hakes accepted from Pennsylvania drill cuttings from "Marcellus Operations," they have misinterpreted this to mean that the drill cuttings are actually from the Marcellus shale formation. That is not the case. Rather, the drill cuttings sent to Hakes were from the vertical portion of the well-bore, not the portion from the kick-off point and into the Marcellus. Therefore, commentators' concerns regarding radiological risk due to acceptance of Marcellus shale drill cuttings are also unfounded because Hakes is not authorized to accept these materials.

KEY ISSUE #2: Concerns Regarding Radiological Effects From Drill Cuttings on the Environment and Those in Close Proximity to the Hakes Landfill

Commentators assert that those who live in proximity to the Hakes Landfill or work at the Landfill are at heightened risk. Commentators assert generalized concerns regarding radiological contamination of groundwater, surface water, and the overall environment due to the disposal of drill cuttings at the Landfill. Commentators believe that this puts local residents and Landfill workers at heightened risk.

RESPONSE TO KEY ISSUE #2:

First, the levels of radioactivity that are allowable for acceptance at Hakes (and other New York landfills) are very low so that even close neighbors would not experience impacts above normal background levels. Part I of this report describes in detail the manner in which radioactivity-related acceptance protocols for the Hakes, Chemung and Hyland Landfills were very conservatively developed, made even more conservative by the NYSDEC and then officially promulgated into regulations. The 25 pCi/g (radium) threshold for incoming waste loads was developed using multiple highly conservative assumptions, including that a person would live and be farming on top of the landfill.

Specifically, the initial radium limits for incoming waste at all three landfills were conservatively set at 25 pCi/g as an annual average and 50 pCi/g for any one truckload. These limits were derived from an extensive radiation dose/risk analysis that assumed the landfill was (1) filled to the permitted capacity, (2) with cutting-type material containing 50 pCi/g of radium (which is far higher than actuality), and (3) a farmer built a home on the landfill and grew crops there (which also would not actually occur). The results of this analysis demonstrated that the resident farmer under these circumstances would not receive a radiation dose in excess of prescribed limits, even assuming a full landfill with drill cuttings containing 50 pCi/g of radium.

However, the NYSDEC wanted to add an additional safety factor and, although allowing acceptance of individual truckloads containing 50 pCi/g, the Department set the limit for an annual average at 25 pCi/g. Subsequently, continuing along a path of extreme conservatism, the NYSDEC eliminated acceptance of single truckloads up to 50 pCi/g, setting the regulatory limit for incoming waste at 25 pCi/g.

Therefore, the Hakes Landfill's acceptance of drill cuttings does not pose an enhanced radiological risk to local residents or Landfill workers. Significantly, the NYSDEC has considered and re-considered, on several occasions, allegations of potential health-related radiological impacts from the disposal of drill cuttings at New York landfills and has consistently found no quantifiable risk to the public, the environment or workers. This is reflected both in the NYSDEC's Responsiveness Summary in the SEQRA process for the Chemung Landfill expansion, as well as in the HVHF FSGEIS. HVHF FSGEIS, Vol. 2, pp. RTC-100 – RTC-101 (**Exhibit C**); 2016 Chemung Responsiveness Summary (Responses #R4, #RMR4, #RP3, #RP15, #H1) (**Exhibit D**). This is also implicitly reflected in the NYSDEC's amended Part 380 regulations and supporting documentation which continue to distinguish between drilling cuttings (as NORM, not regulated under Part 380 and allowable in Part 360/363 facilities) versus TENORM and other types of production wastes (which are not allowable in Part 360/363 facilities), 6 NYCRR 380-1.2(e); 6 NYCRR 380-2.1(a)(66); Part 380 Public Comment Assessment, Responses 1-1 & 4-1.

Second, as to the drill cuttings themselves, even those from the Marcellus shale formation have radium concentrations that are relatively low, just slightly above background levels, and similar to items encountered on a daily basis (such as granite counter tops, red brick, or gypsum that is used in sheetrock, fertilizer and kitty litter, etc.). 2010 CoPhysics Report (**Exhibit B**).

Third, commentators' concerns about environmental contamination also do not account for the engineering features of the Landfill. The Hakes Landfill is lined with an impervious membrane (liner) over a clay layer and has a leachate collection system above the liner system to protect groundwater. Note that the liner and leachate collection systems were installed long before any thought of radionuclide protection. These systems were installed as required by NYSDEC regulations to protect groundwater from the miscellaneous contaminants possible from construction and demolition waste. The low levels of radium in both the drill cuttings and the leachate system demonstrate ample protection of local drinking water wells, as is also confirmed by the low analytical results from monitoring wells surrounding the site. **Exhibits F & G** (data from Hakes from, respectively, 2012-2017 and 2018, showing low levels of radium-226 and radium-228 in leachate).

KEY ISSUE #3: Efficacy of the Gamma Ray Detection Radiation Monitoring System for Incoming Waste Loads

Commentators believe radiation monitoring at the Hakes Landfill of truck loads entering the facility (via gamma ray detection and use of the CoPhysics Truck Monitor Correlation Study conversion factor) is inadequate in that it does not provide a reliable measure of radium-226.

Specifically, commentators assert that in a truckload of drill cuttings, the lack of secular equilibrium between radium-226 and its gamma-ray emitting progeny (due to radon release/loss from the cuttings in the truck) renders the gamma radiation detectors at the Landfill entrance unreliable at detecting radium concentrations. In other words, commentators assert that, due to the escape of radon from the load, there will be a loss of radon's progeny, bismuth-214 and lead-214, which are strong gamma emitters; and this, in turn, could result in truckloads of drill cuttings carrying the same amount of radium to have a 60-fold difference in radium-226 measurements at the Landfill gate.

RESPONSE TO KEY ISSUE #3:

The commentators' conclusion – that gamma ray detectors cannot accurately screen for radium – is incorrect because it is based on an incorrect assumption. The commentators' position assumes that the gaseous decay product (progeny) of radium, namely radon-222, emanates in vast amounts out of open-top truckloads and, therefore, due to this assumed loss of radon, its gamma-ray emitting progeny (lead-214 and bismuth-214) would not be in the truck as it arrives at the Landfill.

In actuality, however, only a small amount of radon is lost from soil (or rock cuttings) when exposed to air. I am highly experienced in performing gamma radiation measurements of radium-bearing soil at radium-contaminated sites. Based on that extensive experience, I can assert with a high degree of professional confidence that there are easily detectable and quantifiable gamma rays emitted from soil even while it has been exposed to air over a long time. In short, the full release of all radon does not occur as the commentators contend.

The commentators' misapprehension arises from confusing the analysis of a small 100-gram soil sample with the measurement of a truckload of rock cuttings. In other words, the commentators are assuming that small soil samples are prepared and handled in the same manner as placing drill cuttings on a truck, and such is not the case.

When soil samples are collected and processed in a laboratory, they are dried in an oven and are homogenized (mixed) in a grinder, which also aerates the soil. In that process, generally more than 50% of the radon trapped in soil particles is driven off. Therefore, to obtain accurate activity measurements, typically, the sample must be sealed in a jar for at least 21 days to allow the radon (and its gamma-emitting progeny, lead-214 and bismuth-214) to build up again from decay of the radium in the sample. (Note that the radium in the sample is unaffected, meaning it

is not driven off, by grinding and heating because radium occurs as an inorganic compound [e.g., salt] and is not volatile.)

In contrast, the mixing, grinding and oven heating used in the preparation of soil samples do not occur with the collection/transport of drill cuttings. And, there is no basis to believe that any appreciable amount of radon will be lost from drill cuttings placed in trucks (in contrast to the case when small soil samples are prepared for analysis). In fact, given the nature of radon and the process by which drill cuttings are collected and transported to the Landfill, only an insignificant loss of radon occurs. More specifically, drill cuttings are obtained by pumping out of the well hole chips of chopped rock (along with the cooling medium) and then slowly pouring this material into a container where the chips are piled up for a period of time. When full, the container is moved aside. If there is some free liquid in the container which is too much for transport, wood chips or similar materials are mixed in with a backhoe. There is no grinding or heating to drive radon out of the rock chips. Surely, some radon emanation occurs from the surface of rock chips exposed to air, but such loss is minor. The containers are then taken to the landfill.

While it is true that 50% or more of the radon and its gamma-emitting decay products can be released from a ground-up, well-aerated and oven-dried soil sample, as described above, truckloads of drilled rock certainly are not aerated and oven dried. Both I and other USEPA contractors have tested the effect of collecting a sample of dry soil, spreading it out and mixing it in a flat pan, then analyzing the gamma emission from the remaining radium progeny in the soil after an hour or so after collection. We have tested this numerous times in order to ensure that a quick analysis of soil without a 21-day radon buildup period could be used to assess a soil sample's radium concentration. We have found that nominally 75% of the radium progeny in a soil sample remains in the sample immediately after at is collected. A correction factor (approximately 1.33) is then applied to the laboratory result to account for the lost 25%, meaning the full amount in the sample ultimately is reported. (We find this procedure is necessary when an excavation crew is waiting for a rapid analysis of a soil sample. This is standard practice at USEPA and US Army Corp of Engineers cleanup sites that have on-site laboratories. Actual correction factors vary from site to site and also vary with moisture content of the soil.)

Considering that a truckload of drill cuttings is not spread out and mixed, I estimate that greater than 90% of the gamma-emitting progeny of radium is present in a load (that is, less than 10% of the radon in a load is lost to the atmosphere). If there is radium in a load, it certainly would be emitting easily detectable gamma radiation. This is a simple, logical and scientifically valid conclusion that would be made by anyone experienced in performing radiation surveys of open land areas at radium-contaminated sites. If there is radium present in soil, whether open to the air or sealed by some cover, it can be easily and accurately assessed using an in-field gamma radiation detector. Whether the soil is in the ground or in a truck, if there is radium present, the soil will be emitting an abundance of gamma rays.

In addition, the radium concentration conversion factor derived in the CoPhysics Truck Monitor Correlation Study **(Exhibit H)** is valid and its application results in properly accounting for all the radium in the load. This study was conducted using an open top load of radium-bearing, dried sludge cake as the calibration source. The calibration material was loosely packed chunks of broken 1-inch thick plates. I estimate a loss of radon from this open top container on the order of 10%, similar to that of loads of drill cuttings or soil. Therefore, any loss of radon occurring by both types of loads is woven into the determination of the radium concentration conversion factor for the type of radiation monitor used at all of the landfills under discussion. That is, both the calibration source (the truck loaded with radium-bearing material) and the unknown samples (the trucks entering the landfill) are very similar, i.e., both are open top containers. Therefore, the radium concentration conversion factor determined in the correlation study is valid and includes the consideration of the small amount of radon loss out of the top of the load. In other words, the ultimate measurements (which employ the conversion factor) account for *all* of the radium in the incoming load.

Based on my extensive degree of professional experience in these matters, I find the commentators' contentions to be unfounded. In my professional opinion, (1) the use of gamma radiation detectors is an entirely appropriate method to screen incoming waste loads (and, in fact, is the state-of-the-art industry standard that has worked in practice at numerous landfills, including Casella's facilities), and (2) application of the conversion factor in the CoPhysics Truck Monitor Correlation Study is valid and results in fully accounting for the amount of radium in the incoming truckload.

KEY ISSUE #4: Concerns that there is More Radium-226 (or Radon-222) in the Hakes Landfill than is Being Measured

Commentators assert that, in leachate from the Hakes and Chemung Landfills, there is a disequilibrium between radium-226 measurements (obtained by employing EPA Method 903.1) and levels of progeny bismuth-214 and lead-214 (obtained by employing EPA Method 901.1). Based on this, commentators believe that there is much more radium-226 or radon-222 than is being measured. Some commentators assert that there is more radium-226; others assert that the disequilibrium means there is more radon-222. In either case, commentators attribute the enhanced levels to the disposal of drill cuttings.

RESPONSE TO KEY ISSUE #4:

In my professional opinion, the radium-226 values obtained from employing EPA Method 903.1 are accurate. The radon-222 concentrations in leachate appear to be much higher than the radium values due to the physical characteristics of these radionuclides (as well as the unreliability of EPA Method 901.1 in accurately measuring bismuth/lead-214 and, therefore, radon-222 in leachate). In other words, the disequilibrium between radium-226 levels and radon

progeny bismuth-214 and lead-214 in leachate does not mean that radium-226 is under-measured in the samples. The concentration of radon in groundwater is much more dependent on the porosity of the ground and the solubility of radon than it is by the amount of radium in the ground.

Higher levels of radon *do not* necessarily indicate high levels of radium. The literature is replete with examples (from throughout the country) where groundwater is found to contain thousands of times greater radon levels than that of radium. This phenomenon occurs whether the groundwater is sampled from drinking water wells, natural springs, or leachate collection systems. The reason for this natural effect is that radon is thousands of times more soluble and migratory in water than is radium, and, therefore, radon leaches out of soil thousands of times faster than radium. This is reflected in USEPA regulatory limits for drinking water: 5 pCi/L for radium-226 and 4000 pCi/L for radon-222. (These well-known USEPA limits demonstrate both that radon is much less hazardous than radium and that, in groundwater, radon normally occurs at much higher concentrations than radium.) Of course, the leachate at the Hakes Landfill is not drinking water.

Even with these naturally-occurring-higher levels of radon in leachate, radon in discharge water (as effluent or sewer) is not a public health or regulatory control problem because radon-222's half-life is so short (~3.8 days) that it decays away before reaching any water supply; and, notably, Part 380-11.7 does not contain a regulatory standard for release of radon-222 in effluent or sewer discharge. In fact, Part 380 (as amended) confirms that radon (except as a decay product of source or special nuclear material, which is not at issue here) is NORM, part of background radiation, and not subject to regulation. 6 NYCRR 380-1.2(c) & (e); 6 NYCRR 380-2.1(a)(8). In any event, based on this widespread, well-known phenomenon, it is reasonable to conclude – without additional testing – that the reason for the disparity between radon and radium concentrations in Hakes leachate is due to radon's solubility.

Finally, it cannot be over-stated that the higher ratios of radon-to-radium in the leachate are not attributable solely to the Landfill (let alone drill cuttings) – this effect occurs naturally in nearly all groundwater samples across the country. This, EPA Method 901.1, and the issue of how much radon-222 is actually in Hakes leachate are further discussed below.

KEY ISSUE #5: Concerns Regarding High Levels of Radon-222 (or its Progeny) in Leachate or Air.

Commentators assert that there is a "trend" of increasing radioactivity in leachate from the Hakes (and Chemung) Landfills, with particular concern being high levels of radon-222. They point to a sample from cell #5 taken in 2014 and another sample from cell #8 taken in 2017, which measured approximately 6000 pCi/L of bismuth-214 and lead-214 (which are

progeny of radon-222). Since, after collection, the samples had been sealed for 21 days to reach equilibrium, commentators assert that given the short half-life of parent radon-222 (3.8 days), there had to be levels of radon-222 much higher than 6000+ pCi/L when the samples were collected. Back-calculating to account for the decay of radon-222 (from the time of sample collection to 21 days thereafter), commentators assert that the radon level at the time of sampling was 275,000 pCi/L. They also assert that this means that radon in the air/landfill gas mixture could have been as high as 1.05 million pCi/L.

With respect to radon, commentators express environmental/health concerns regarding the effects of high levels of radon in leachate and airborne emissions (flaring, vents, downwind effects, "nuclear fallout"). Specifically, they assert that radon-222 associated with the disposal of drill cuttings at the Hakes and Chemung Landfills (airborne and in leachate) presents an increased environmental risk and enhanced cancer risk to the public, as well as an increased risk of birth defects and a shortened life span (for example, due to inhalation, migration through groundwater, drinking water wells, taking hot showers, migration into basements, and dust particles).

In addition, some commentators express concern that the longer-lived progeny of radon-222, lead-210 and polonium-210, in leachate from the Hakes and Chemung Landfills present health concerns and should be characterized to prevent adverse environmental impacts.

And, commentators attribute the asserted elevated levels of radioactivity to the disposal of drill cuttings.

RESPONSE TO KEY ISSUE #5:

It is true that two leachate samples collected from Hakes Cell #5 on 11/11/14 and Hakes Cell #8 on 6/6/17, measuring approximately 6000 pCi/L of bismuth-214 and lead-214 (radon progeny), are unusually high relative to other leachate samples. Taking the higher cell #5 values and back-calculating (decay-correcting) from the analysis time to the time of collection results in an approximate bismuth-214, lead-214 and radon-222 concentration of 275,000 pCi/L, which sounds like a very high value to a layman. However, these discrete values need to be put in perspective. In this regard, there are three points to make:

1. Past leachate sampling and analysis methods were never designed to be used for radon assessment. I have discussed these unusual results with the manager of the analysis laboratory. He believes there is so much uncertainty in this type of analysis that, to make a decay correction of several orders of magnitude would result in a multiplication of the uncertainties to unreliable levels. So, the 275,000 pCi/L calculation cannot be relied upon as an accurate estimation of radon and progeny in the original on-site samples.
2. Even if the 275,000 pCi/L calculation were accurate, however, it would not present health or regulatory problems since this level would be only 9% of the bismuth-214

limit and only 28% of the lead-214 limit for discharges to sewers.

3. The unusual results are certainly reason to conduct further investigation of the issue, including analysis for lead-210 which is the longer-lived decay product of radon-222. As discussed below, however, that investigation has been performed and reveals very low levels of lead-210, further demonstrating that the back-calculated radon result (275,000 pCi/L) is unreliable.

These points are further discussed as follows:

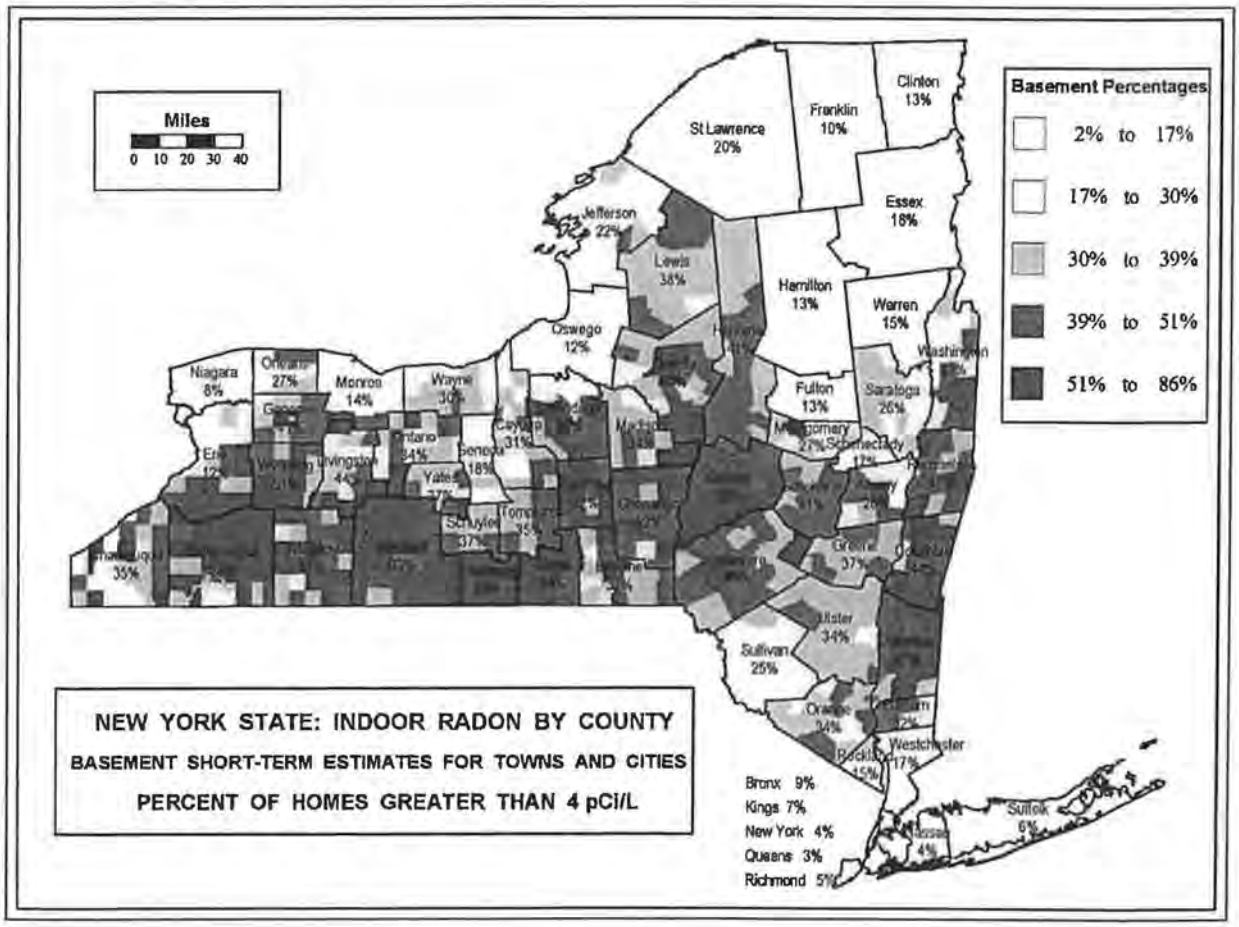
The analysis method (EPA 901.1) used for leachate analysis in the past (and for the lead-214 and bismuth-214 values that are at issue here) is a soil analysis method and, when used to analyze a water sample, produces very inconsistent and possibly erroneous results. In fact, the NYSDEC has recognized the problems with the EPA 901.1 method for water analysis as reflected by their removal of the requirement for its use in the recent (September, 2017) modification of its landfill regulation (6 NYCRR Parts 360 & 363). The radiochemical and emanation methods for radium analysis (EPA 903.1 and 904.0) are far more sensitive and accurate and will continue to be used. If the NYSDEC wishes radon in water to be analyzed, then a radon-specific test method should be used, such as ASTM D5072. In other words, the 6000 pCi/L values for bismuth-214 and lead-214 obtained utilizing EPA 901.1 are unreliable and do not provide an accurate measure of actual activity levels.

In addition, if one applies a quantitative decay correction factor using collection and analysis data not intended for such purpose, that greatly compounds the errors. Therefore, the back-calculated value of 275,000 pCi/L of radon in the leachate cannot be used to make any quantitative, regulatory, or health effects judgments. The result only can be used as an indicator that higher radon levels *may* exist in the leachate, which *may* be cause for further or different types of sampling. (And, as discussed below, additional sampling was performed, with the results demonstrating that the back-calculated bismuth/lead/radon value is inaccurate.)

For the sake of discussion, even if we assume the apparently high value is relatively correct, we can at least compare this magnitude to the regulatory limits: 3,000,000 pCi/L bismuth-214 and 1,000,000 pCi/L lead-214 for monthly release to sewers. Therefore, this apparently high, back-calculated radioactivity level in leachate (275,000 pCi/L), if correct, would be actually only 9% of the bismuth-214 limit and only 28% of the lead-214 limit if that sampling point was the only point released to the sewer. When averaged over all of the other leachate collection points contributing to the sewer discharge, the average bismuth-214 and lead-214 release levels would be at an even smaller fraction of the monthly sewer release limits.

While some of these radon progeny results in leachate appear to be high to the layman, they are actually within the range of natural background, albeit probably at the higher end of the range. This is to be expected since the Steuben County geology has been known to have higher levels of radon in soil gas than most other areas of the State. In the radon map below, published

by the NYS Department of Health, note that the natural radon exposure of the Steuben County public is quite elevated compared to the rest of the State in that 63% of the homes have natural radon concentrations exceeding the USEPA guideline. Also note that the map displays radon in air while we are discussing radon in water; however, the two are related to the same geologic properties of the region.



Even with apparently-elevated naturally occurring levels of radon in leachate, radon in sewer water is not a public health or regulatory control problem because radon-222's half-life is so short (3.8 days) that it decays away before reaching any water supply. Note that there is no federal or NYS regulatory limit for radon in effluent discharge or sewer discharge, e.g., 6 NYCRR 380-11.7 (no effluent or sewer discharge limit for radon is listed). And, Part 380 further confirms that the radon at issue here is NORM, part of natural background and not subject to regulation. 6 NYCRR 380-1.2(c) & (e); 6 NYCRR 380-2.1(a)(8).

As for commentators' concerns regarding airborne releases of radon from the Landfill,

allegations of downwind "nuclear fallout" effects, and claims of radon migration and infiltration into people's homes from the Landfill, the physical properties of radon and controls/procedures in place at the Landfill belie any such impacts. Regarding dust-related and other airborne emissions of radon, landfills (including the Hakes Landfill) are not significant sources of downwind airborne radon. Soil cover used at the Landfill is clean soil and also has nothing to do with the drill cuttings, muds, and C&D waste being accepted for disposal. Airborne emission of radon-222 from the Landfill is simply a natural occurrence from the native, local soils used as a cap, just as would happen in an open field. However, there is a confounding feature of landfills that does not exist in open fields: namely, landfill gas vents and flares. While there certainly would be higher concentrations of radon in the gas released from vents and flares, the volume of gas released is very small. These small but concentrated discharge points when averaged over the area of the Landfill do not pose a downwind hazard due to rapid mixing and dilution in the atmosphere. This point source dilution is the same technique used for residential radon mitigation systems where high levels of radon from the sub-foundation are discharged through a pipe above the home's roof line. Relative to the radon exposure occurring in homes with or without mitigation systems, downwind radon exposures from landfills are extremely minor. Indeed, given radon's physical properties (for example, short half-life, rapid mixing/dilution in the atmosphere), to the extent local residents' homes were found to have enhanced levels of radon, such would result from radon emanating from soils on the homeowner's own property, and not the migration of radon from the Landfill hundreds of yards away. And, as already noted, per Part 380, radon is NORM, part of natural background, and not subject to regulation as a radioactive material under Part 380. 6 NYCRR 380-1.2(c) & (e); 6 NYCRR 380-2.1(a)(8); Part 380 Public Comment Assessment, Response 17-5 (which states that "[t]he constraint on radioactive emissions in Part 380 [radiation dose constraint for airborne emissions] does not include NORM, such as radon"); Responses 14-1, 15-4, 15-5, 15-6, 15-17 (all of which state that Part 380 regulates TENORM, not NORM).

As for potential groundwater-related impacts from radon, the Landfill's liner, leachate collection system, and monitoring protocols protect groundwater resources. This is discussed in Response to Key Issue #2, above. In addition, to the extent that the two cited leachate samples (one from 2014 and one from 2017) appear to contain elevated radon, it bears repeating that there is no regulatory limit for radon in discharge water (sewer or effluent); and, leachate in discharge water is certainly not used for drinking water.

Certain commentators have claimed potential impacts from radon's longer lived progeny, lead-210 and polonium-210. If the radon concentration in leachate were at a steady-state level of 275,000 pCi/L, then the lead-210 concentration should be at an equilibrium value of 130 pCi/L, which would exceed the monthly discharge limit of 100 pCi/L. To investigate this issue, Casella performed additional sampling and analyses. Sample results of leachate from 6 cells collected in February of 2018 show levels of lead-210 ranging from 0.11 to 0.62 pCi/L (**Exhibit G**). (Polonium-210 levels would be less than or equal to the lead-210 levels since they are normally

in equilibrium.) These relatively low lead-210 results serve to prove that the actual radon levels in the leachate are far less than the very rough calculational level of 275,000 pCi/L, and the results of EPA 901.1 should be rejected. There are certainly elevated levels of radon in leachate as there are in any groundwater sample, but not to the extent suggested by the commentators.

Finally, in my professional opinion, which I can assert to a reasonable degree of scientific certainty, there is "no cause and effect" between the disposal of drill cuttings and radon-222 levels in leachate. Rather, radon is a natural occurrence and not the result of drill cuttings being disposed there. The drill cuttings in the Hakes Landfill account for less than 11 percent of the waste and overburden deposited to date at the facility and, at worst, have only slightly higher radium levels than background; thus, drill cuttings are only a small portion of the source of the radon. To the extent that radon-222 exists in the leachate, this is a natural occurrence due to both the native, local soils, clay and gravel that are used to construct the Landfill and the C&D materials deposited in the Landfill (such as brick, sheetrock, concrete block, wood ash, coal ash, etc.), which are also sources of radon. The radon in leachate comes from all of these Landfill constituents which have radium concentrations on the order of 1 to 10 pCi/g. And, we know from the NYS Department of Health's published data, this whole region is prone to elevated radon levels. Also relative to the Hakes Landfill, the concentration of radon in leachate may be further enhanced by the fact that the Landfill materials have more air spaces than does undisturbed soil. Natural radon would build up in these spaces, and this is so whether the surrounding material is drill cuttings, C&D waste, gravel or fluffed native soil. As rainwater infiltrates through these spaces, radon dissolves into the water more so than rainwater infiltrating through native, settled undisturbed soil. Therefore, some level of radon concentration in Landfill leachate should be expected.

In the end, it is important to reiterate that the naturally-occurring levels of radioactivity in the leachate are due to all of the materials in the Landfill, including the indigenous soil and rock from the Steuben County area and C&D materials such as brick, sheetrock, concrete block, ash, drill cuttings, etc. These are all sources of radium and radon contributing to that found in the leachate, and there is no scientific basis to conclude that the measured levels are a result of solely drill cutting disposal.

KEY ISSUE #6: Concerns that any level of exposure to ionizing radiation has negative health consequences (aka, the linear-no-threshold model, or linear-dose relationship between exposure and health impacts)

Commentators believe that any level of exposure to ionizing radiation enhances health risk and, therefore, should not be permitted. More specifically, commentators assert that there is a linear-dose relationship between exposure and health impacts; in other words, there is no threshold at which exposure to radiation, even at very low doses, will fail to negatively affect health.

RESPONSE TO KEY ISSUE #6:

It is true that government policy assumes a linear no threshold dose-response relationship between exposure and cancer. This policy, however, is merely a very conservative assumption adopted for the purpose of developing extraordinarily safe regulations. Importantly, in a variety of contexts (including relative to medical imaging), the linear no threshold dose-response relationship for low dose radiation has been severely criticized as lacking any statistically sound supporting data and being premised on a flawed scientific foundation. **Exhibit I** is a report by Edward J. Calabrese and Michael K. O'Connor (2014), Estimating Risk of Low Radiation Doses – A Critical Review of the BEIR VII Report and its Use of the Linear No-Threshold (LNT) Hypothesis. Radiation Research: November 2014, Vol. 182, No. 5. In this report, at pp. 463-474, the authors provide a historical review of the BEIR VII Report, explain the underlying bases for the LNT relationship, and also explain the many defects, flaws, limitations and criticisms regarding application of the LNT relationship to low dose exposure.

It is important to recognize that the linear dose-response relationship at low levels of radiation exposure has never been observed in fact. For example, the background radiation exposure of people living on the east coast is about 100 millirem/year, whereas the exposure of people in Colorado is about 250 millirem per year due to the reduced shielding of the atmosphere to cosmic radiation (i.e., "mile-high city") and due to the higher levels of radium, uranium and thorium in the Rocky Mountain area geology. Therefore, Coloradans receive 250% more of a radiation dose than we receive on the east coast; yet, Coloradans' cancer rates are less than or equal to ours. Centers for Disease Control Data (2014), https://www.cdc.gov/cancer/dcpc/data/state.htm. If there were truly a linear relationship between radiation exposure and cancer, Colorado residents would have a higher incidence of cancer than east coast residents, but that is not the case.

While present science does not tell us exactly the effect of low doses of radiation, numerous scientific organizations have (1) soundly rejected the LNT relationship for low dose exposure, and (2) concluded that the low dose effect is very small or zero and is not detectable even in studies of large groups of individuals. As is noted above, the report by Edward J. Calabrese and Michael K. O'Connor (2014), Estimating Risk of Low Radiation Doses – A Critical Review of the BEIR VII Report and its Use of the Linear No-Threshold (LNT) Hypothesis. Radiation Research: November 2014, Vol. 182, No. 5 (**Exhibit I**) disputes the hypothesis of the commentators and concludes that "the [LNT] model ...should not be used for estimating risks from low doses of radiation."

EXHIBIT A

Guevara, Yasmin X (DEC)

From: Maslanka, Gary M (DEC)
Sent: Thursday, January 21, 2010 1:28 PM
To: Joe Boyles
Cc: Carla Canjar; Domagala, Mark (DEC); Amann, Mark (DEC); Foti, Scott J (DEC)
Subject: Re: Fw: Ignitability
Attachments: TEXT.htm; IMAGE.gif; IMAGE.gif; IMAGE.gif; IMAGE.gif; IMAGE.gif; IMAGE.gif; IMAGE.gif; IMAGE.gif

Joe,

I've reviewed the information you provided on the gas well drill cutting from Fortuna. Based on the analytical data provided, and the letter provided by Benchmark Analytics, Inc addressing the ignitability value initially reported, the drill cuttings from Fortuna may be dispose of in the Chemung MSW landfill.

Be aware, cutting from wells utilizing oil based cutting fluids may be disposed of in the **MSW landfill only.**

Cutting generated from wells using water based cutting fluids may be disposed of in the MSW or C&D landfill.

Please remember these materials are not consider BUD waste. As such all cuttings will count toward the C&D or MSW tonnage limits.

Please call me if you have any questions.

>>> Joe Boyles <Joe.Boyles@CASELLA.COM> 1/20/2010 11:21 AM >>>

Gary: I believe that we have this covered.

Larry said that Chemung is not interested in using this as a BUD. Do we have your approval to being this in as a waste?

(See attached file: KMBT35020100120083048.pdf)

---- Forwarded by Joe Boyles/CASELLA WASTE SYSTEMS INC/US on 01/20/2010 11:18 AM ----

"c.young"
<c.young@benchmarkanalyticslabs.com>

01/20/2010 11:08 AM

Please respond to
<c.young@benchmarkanalyticslabs.com>

To"'Joe Boyles'"
<Joe.Boyles@CASELLA.COM>

cc<geowetlands@aol.com>

SubjectRE: Ignitability

I checked with QC Laboratories about their temperatures and they use and they use a propane torch which can achieve a temperature of about 190°F or higher.

I looked back at all past samples sent in for ignitability from United Environmental Group and found only two additional

EXHIBIT B

CoPhysics CORPORATION

Radiological Survey Report

Marcellus Shale Drilling Cuttings

from Tioga and Bradford Counties, Pa.
and
New England Waste Services of N.Y., Inc. Landfill Sites in
Chemung, NY
Campbell, NY
Angelica, NY

April 2010

Performed by:

CoPhysics Corporation
1242 Route 208
Monroe, NY 10950

Theodore E Rahon

Date: 4/26/2010

Theodore E. Rahon, Ph.D.
Certified Health Physicist

Introduction

New England Waste Services of N.Y., Inc. (NEWSNY) operates 3 landfills in the southern tier area of New York State. In the last several years, these landfills have accepted natural gas-related drill cuttings from several wells in New York and Pennsylvania. (Drill cuttings are the ground rock resulting from the drill bit's penetration into the earth.) More recently, deeper Marcellus shale cuttings have been accepted from drilling operations in northern Pennsylvania. Oil and gas companies have been disposing of approximately 1000 to 2000 tons per week of cuttings in the nearby NEWSNY landfills as well as significant quantities in other landfills in Pennsylvania.

Recent advancement in horizontal drilling technology has led to increased interest by the oil and gas industry in Marcellus shale development, both in Pennsylvania and New York State. Possible radioactivity in the drilling process waste streams is receiving public and regulatory scrutiny. Most studies to date have focused on the liquid discharges, termed "produced water", from the gas wells rather than on the drill cuttings. NEWSNY has confirmed that their landfills do not accept liquid waste, produced water, or sludge. Because of the lack of radioactivity data on the rock itself, NEWSNY has contracted CoPhysics Corporation to conduct a radiological investigation of the rock to determine the appropriateness of accepting the drill cutting waste from Marcellus shale for disposal in its New York, non-hazardous, solid waste landfills.

CoPhysics Corporation is a radiological science consulting firm located in Orange County, NY. It is licensed to handle radioactive materials and provide radiological services by the NYS Department of Health. It conducts specialized radiological assessments for government, academia, and business.. The owner is Theodore E. Rahon, Ph.D., a Certified Health Physicist with over 30 years of experience in radiation protection, especially decommissioning and assessment of radium- and thorium-contaminated sites. He has consulted for the USEPA, the Army Corp. of Engineers, several state and local governmental authorities, and numerous university and industrial clients.

Natural Radioactivity

There are 3 main groups of radioactive elements making up the natural radioactivity background in the earth's crust: the uranium-238/radium-226 radionuclide series, the thorium-232 radionuclide series, and potassium-40. These exist in all soil and rock in varying concentrations. There are also minor levels of other radionuclides in soil but these are not important from an environmental health standpoint and will not be discussed here.

The unit of measure for the concentration of radioactivity in soil is picocuries per gram (pCi/g). Typical natural background concentrations of uranium, radium, and thorium in soil and rock in the eastern US are 0.5 to 1 pCi/g each. Some clays are in the range of 1 to 3 pCi/g. Certain commercial minerals, such as gypsum (used for fertilizer and drywall), zirconium and titanium (used in paint), zircon sand & carborundum (used in grinding wheels, sandblasting, and ceramics), are in the range of 5 to 50 pCi/g.

If the concentration of uranium, radium or thorium is much higher than background, the material is termed "NORM", naturally-occurring radioactive material.[1]

The third predominate, naturally-occurring radioactive material is radiopotassium (K-40) which typically ranges from 10 to 30 pCi/g in soil. Potassium-40 is ubiquitous in all potassium-containing materials, including our bodies. It is not commonly regulated.

The accepted safe level for radium and thorium in soil on which homes, schools, and businesses could be built is 5 pCi/g above local background for surface soil and 15 pCi/g for soil greater than 6" deep. This guideline was originally specified for radium-226 in soil around uranium mill sites by the USEPA in 40CFR192. This guideline has been adopted for most cleanup sites across the US for radium and thorium whether or not the site is associated with a uranium mill. Restrictive limits for NORM in landfills have ranged up to 50 pCi/g depending on the state and municipality. In New York, NORM is exempted from regulation under 6 NYCRR Part 380.

Therefore, the purpose of this study is to determine if the gas drilling cuttings have radioactivity in the normal, natural background range or would be considered to be NORM. And, if the cuttings are NORM, at what level would the elevated radioactivity concentrations affect the local environment in and around the landfills.

Methodology

To begin the project, NEWSNY management requested that an initial, early-stage round of sampling be scheduled so that information could be obtained quickly. Such an initial survey is usually termed a "scoping" survey. This would give NEWSNY the ability to modify or limit its acceptance of the drill cuttings as appropriate if high levels of NORM were found. Based on the initial sampling results, additional measurements later could be specified to better characterize any areas of interest that require more in-depth evaluation or a "no further action" designation could be applied to the situation if scoping measurements did not show elevated levels of radioactivity.

To assess the drill cutting waste relative to local background radioactivity, CoPhysics collected three (3) types of samples:

- On-site soils (Collected to establish background radioactivity levels in natural soil and rock in the local landfill area. Both surface samples and subsurface samples from existing monitoring wells were collected.)
- Drill cuttings as delivered to the disposal facility (These were collected to investigate radioactivity levels in material as received. The sample from the pile exhibiting the highest on-site gamma reading was chosen for laboratory analysis.)

[1] This report does not address the extent to which NORM is regulated as a radioactive waste, but rather the extent to which Marcellus shale drill cuttings present a public health concern based upon USEPA cleanup levels for NORM to achieve unrestricted use of property for homes, schools and businesses. A discussion of regulatory standards and exemptions for NORM is beyond the scope of this report.

- Confirmed Marcellus shale samples collected at rig sites in nearby Pennsylvania (The rig sites were geographically separate locations and operated by more than one drilling company. Additional information about the rig site sample was also obtained such as depth of drilling at the time of collection, the geologic formation, the lateral distance into the formation, type of fluid used, etc.)

Samples were analyzed via gamma spectroscopy for the 3 main radionuclides in the naturally-occurring groups: radium-226, thorium-232, and potassium-40. During sample collection, *in situ* gamma radiation measurements were also performed using a hand-held Ludlum Model 12S instrument so that a wider indication of shale-associated radiation levels could be obtained.

Description of Measurements Performed

On March 2, 2010, personnel from CoPhysics Corporation visited the 3 NEWSNY landfills to collect indigenous soil and rock samples and to perform ambient gamma radiation measurements. The field data collected are shown in Appendix B. The data sheets show the locations of sample collection on an aerial photo of each landfill. The CoPhysics field technician collected three types of samples from the landfills; 1) previously collected soil samples from monitoring well drilling , archived by NEWSNY, were obtained as background radioactivity samples, 2) native soil and rock samples from the borrow area, also obtained as background samples, and 3) samples from drill cutting loads recently deposited in the landfill. The local background samples and the cuttings sample that showed the highest field gamma reading were later analyzed via gamma spectroscopy to determine radionuclide concentrations (pCi/g).

On March 11, 2010, personnel from CoPhysics Corporation visited 3 drilling rigs in Bradford County, Pa. and on March 19, 2010, visited a fourth rig in Tioga County, Pa. The four oil and gas company drilling sites visited use sensory technology linked to a computer system to monitor and record drilling activity. The rig operator was able to provide information, pertinent to this assessment, such as depth, lateral distance, etc. from the computerized, real time data acquisition system at the site. Rock cuttings were sampled at the point of discharge from the rigs. Fresh piles of the cuttings were scanned with the Ludlum model 12S gamma radiation detector. As a relative comparison, local background readings were also recorded.

Analysis

The samples collected were analyzed via gamma spectroscopy at the CoPhysics laboratory. Analysis instrumentation consisted of a Princeton GammaTech HPGe detector and Ortec PC-based Trump multichannel analyzer. Instrument calibrations are maintained using NIST-traceable radioactivity standards and laboratory intercomparison samples from the International Atomic Energy Agency (IAEA) and the former US Department of Energy's Environmental Measurements Laboratory.

Samples were analyzed in their "as collected" or *in situ* state, i.e., samples were not dried or concentrated before analysis. However, they were ground into a more homogenous mixture for placement into an analysis geometry that matched calibration standard geometry. The determination of *in situ* concentrations allows the results to be used more appropriately in environmental transport analysis and dose assessments.

Drill cutting sample consistency ranged from a fine mixture (cement-like) to larger particle sizes (up to 0.5 cm) which were slightly moist with cutting fluid. Background soil samples appeared to be of a dry clay-like consistency. Background rock samples collected consisted of pieces of surface shale.

Results and Discussion:

Results from sample analysis, local gamma readings, depth of collection, and other data are shown in Appendix A. The results are separated into 2 groups: drill cuttings and background soil/rock. Also shown for comparison purposes are radionuclide concentrations in common building and industrial materials. The results shown in Appendix A are summarized below in Table 1:

Table 1 - Summary of Radionuclide Analysis Results

Material Type	Average Radionuclide Concentration ± 1 SE		
	Radium-226 (pCi/g)	Thorium-232 (pCi/g)	Potassium-40 (pCi/g)
Gas Drill Rig Cuttings	2.1 ± 1.2	0.7 ± 0.3	14.2 ± 4.8
Landfill Local Background Soil and Rock	0.9 ± 0.1	1.2 ± 0.2	24.1 ± 4.8
EPA recommended cleanup level (40CFR192):	5 over bkg	5 over bkg	not regulated
Typical landfill limits for NORM:	5 to 50	5 to 50	not regulated

Table 1 shows that the Pennsylvania drill cuttings sampled during this project have radium-226 concentrations that are slightly greater than the local background at the New York NEWSNY sites. Conversely, the thorium-232 and radiopotassium levels in the Pennsylvania cuttings are less than New York site background. While the radium levels are slightly greater than background, they do not necessitate the classification of the cuttings as NORM. The radium levels observed are less than the EPA cleanup guideline for unrestrictive use (< 5 pCi/g above background). The EPA uses this guideline for cleanups of sites contaminated with radium or thorium so that they may be used by the general public for homes, schools, businesses, etc.

The rock cuttings from the gas drilling operations, as sampled during this project, have radionuclide levels that do not pose any environmental health problem even if they were deposited in areas accessible by the general public. Therefore they are certainly acceptable for landfill disposal.

However, pipe scale, brine filtrates and associated sludges, not considered in this study, have been known to contain elevated levels of NORM. It was not the purpose of this study to evaluate those materials. To prevent disposal of such materials at its landfills, NEWSNY has ordered the installation of the most sensitive gamma radiation detection system available (Ludlum Measurements, Inc. Model 375-1000) at its truck scales. The purpose of the detection system is to ensure that only the acceptable drill cutting rock is received and no pipe scale, filtrates or sludges containing NORM are inadvertently disposed. After installation, CoPhysics will perform calibration of the monitors' alarms so that any levels of radioactivity exceeding regulatory limits are appropriately detected. CoPhysics will also assist in procedure development and training as necessary to ensure proper use of the monitors.

Given the very low levels of radioactivity found in the Marcellus drill cuttings during this investigation and the landfill's installation of portal radiation monitors as additional assurance against acceptance of NORM, no further study by NEWSNY is warranted.

Appendix A - Radioactivity Measurement Results - Marcellus Shale Drill Rig Cuttings - March, 2010

LAB	Sample#	Date	Sample Location	Material Type	Depth	Gamma[1]	Radionuclide Concentration[2] ± 1 SD								
ID#		Collected			(feet)	(uR/hr)	Radium-226 (pCi/g)			Thorium-232 (pCi/g)			Potassium-40 (pCi/g)		
Gas Drill Rig Cuttings															
738-1	31110A	3/11/2010	Bradford Co., Pa.	Marcellus shale	5942	8 / 10	2.4	±	0.2	0.5	±	0.1	12.9	±	1.0
738-2	31110B	3/11/2010	Bradford Co., Pa.	Hamilton Limestone	6562	5 / 5 [3]	1.1	±	0.1	0.9	±	0.1	17.8	±	1.0
738-3	31110C	3/11/2010	Bradford Co., Pa.	Marcellus shale	6687	11 / 8	4.3	±	0.2	0.9	±	0.1	16.8	±	0.9
738-5	31910A	3/19/2010	Tioga County, Pa.	Marcellus shale	6101	5 / 10	2.8	±	0.2	0.9	±	0.1	17.4	±	1.0
738-6	31910B	3/19/2010	Tioga County, Pa.	Marc. shale with Bayrite	6101	5 / 10	0.6	±	0.1	0.2	±	0.0	3.4	±	0.2
738-13	1-M1	3/2/2010	Landfill, Lowman, NY	transported gas rig cuttings	unk.	12 / 5	2.3	±	0.1	0.7	±	0.1	17.2	±	1.1
738-11	2-M2	3/2/2010	Landfill, Painted Post, NY	transported gas rig cuttings	unk.	12 / 8	0.9	±	0.1	1.2	±	0.1	16.7	±	1.1
738-12	3-M1	3/2/2010	Landfill, Angelica, NY	transported gas rig cuttings	unk.	12 / 8	2.7	±	0.2	0.8	±	0.1	12.6	±	0.8
					AVERAGE ± 1 SE :		**2.1**	**±**	**1.2**	**0.7**	**±**	**0.3**	**14.2**	**±**	**4.8**
Landfill Local Background Soil and Rock															
738-16	1-LS1	3/2/2010	Landfill, Lowman, NY	local soil	0 - 1	16	1.0	±	0.1	1.5	±	0.2	20.2	±	1.4
738-7	1-LR1	3/2/2010	Landfill, Lowman, NY	local rock	1	17	1.0	±	0.1	1.5	±	0.2	16.9	±	1.1
738-17	1-W1	3/2/2010	Landfill, Lowman, NY	local well cutting MW23	22-70	7 / 5	0.9	±	0.1	1.6	±	0.2	20.1	±	1.4
738-18	1-W2	3/2/2010	Landfill, Lowman, NY	local well cutting EB04	37	7.5 / 5	0.5	±	0.1	0.9	±	0.1	8.2	±	0.6
738-15	2-LS1	3/2/2010	Landfill, Painted Post, NY	local soil	0 - 1	22	1.1	±	0.1	1.6	±	0.2	18.2	±	1.2
738-14	2-LR1	3/2/2010	Landfill, Painted Post, NY	local rock	8	22	0.8	±	0.1	1.1	±	0.1	16.4	±	0.8
738-19	2-W1	3/2/2010	Landfill, Painted Post, NY	local well cutting MW03	10-12	6.5 / 8	0.9	±	0.1	1.1	±	0.1	24.4	±	1.7
738-20	2-W2	3/2/2010	Landfill, Painted Post, NY	local well cutting MW0	28-30	6.5 / 8	1.1	±	0.1	1.4	±	0.1	26.1	±	1.4
738-10	3-LS1	3/2/2010	Landfill, Angelica, NY	local soil	6	22	0.8	±	0.1	1.0	±	0.1	24.9	±	1.3
738-4	3-LR1	3/2/2010	Landfill, Angelica, NY	local rock	6	22	0.8	±	0.1	1.0	±	0.1	30.2	±	1.5
738-8	3-W1	3/2/2010	Landfill, Angelica, NY	local well cutting MW47A	18-20	5.5 / 8	1.0	±	0.1	1.2	±	0.1	29.3	±	1.5
738-9	3-W2	3/2/2010	Landfill, Angelica, NY	local well cutting MW42A	30-32	5.5 / 8	0.8	±	0.1	1.1	±	0.1	23.1	±	1.2
					AVERAGE ± 1 SE :		**0.9**	**±**	**0.1**	**1.2**	**±**	**0.2**	**24.1**	**±**	**4.8**
Comparisons															
yellow brick			purchased Orange Co, NY	yellow brick (fire brick)			4.3	±	0.5	5.4	±	0.6	31.9	±	3.1
red brick			purchased Orange Co, NY	red brick			1.1	±	0.1	1.1	±	0.1	25.8	±	1.3
705-5			steel working factory	grinding wheel			2.3	±	0.1	2.8	±	0.2	n/a	±	
705-9			steel working factory	800 Grit sand blast media			19.1	±	1.0	27.2	±	1.5	n/a	±	
				EPA recommended cleanup level (40CFR192):			5 over bkg			5 over bkg			not regulated		
				Typical landfill limits for NORM:			5 to 50			5 to 50			not regulated		

Method: gamma spectroscopy, EPA 901.1 modified
Instrument: Princeton Gamma-Tech Model NIGC-RG15 HPGe detector; Ortec Trump MCA
Uncertainties are based on 1-sigma counting errors and standardization uncertainty.
Standards are traceable to the National Institute of Standards and Technology.
Radioactive Materials License: NYS 2691-3949
Ra-226 via Bi-214; Th-232 via Ac-228 gamma-ray lines

Footnotes:
1 - *In situ* Gamma Exposure Rate
(1-foot from sample collection / local bkg)

2 - per gram as collected (no drying or sample concentration performed)

3 - measurement for 31110B was high up on drill rig, at the cuttings shake

Appendix B - Soil Sampling Field Data Sheets

Soil Sampling - Field Data Sheet

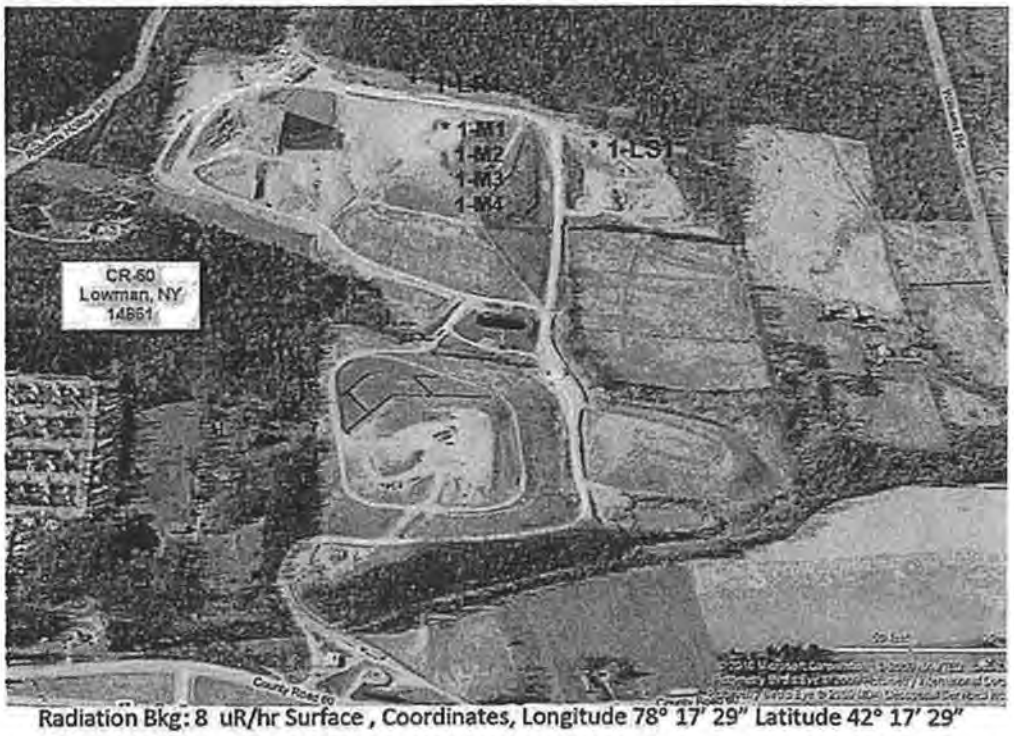
CoPhysics Corporation

Location: CR-60, Lowman, NY 14861

Date: 03/02/2010

Time Arrived: 10:30 AM **Time Departed: 12:30 PM**

Larry Shilling, Landfill District Manager \ Karen Flanders, EH&S
Office # (585) 466-7271
Cell # (716) 560-7915 **8 total samples**



Radiation Bkg: 8 uR/hr Surface , Coordinates, Longitude 78° 17' 29" Latitude 42° 17' 29"

Manufacturer	Model	Serial	Probe Model / Serial	Cal. Date
Ludlum	12	83334	44-2 / 83334A	1/19/2010

Sample No.	Type	uR/hr	Depth
1-LS1	Local Soil 1	15	SURFACE TO 4'
1-W1	Well Cuttings 1	7	MW23 22-70'
1-W2	Well Cuttings 2	7.5	EB-04 37'
1-LR1	Local Rock Sample 1	17	SURFACE TO 6 '
1-M1	Marcellus Shale sample 1	10	cell 3A, black
1-M2	Marcellus Shale sample 1	10	grey
1-M3	Marcellus Shale sample 1	10	grey
1-M4	Marcellus Shale sample 1	10	black

Soil Sampling - Field Data Sheet

CoPhysics Corporation

Location: 4376 Manning Ridge Rd, Painted Post, NY 14870

Date: 03/02/2010

Time Arrived: 1:20 PM **Time Departed: 3:00 PM**

Larry Shilling, Landfill District Manager \ Karen Flanders, EH&S
Office # (585) 466-7271
Cell # (716) 560-7915 **7 total samples**

Bkg. 8 uR/hr at Surface, Coordinates, Longitude 77° 06' 46" Latitude 42° 12' 07"

Manufacturer	Model	Serial	Probe Model / Serial	Cal. Date
Ludlum	12	83334	44-2 / 83334A	1/19/2010

Sample No.	Type	uR/hr	Depth
2-LS1	Local Soil 1	22	Surface to 1'
2-W1	Well Cuttings 1	6.5	MWH-03 IN ORGINAL JAR
2-W2	Well Cuttings 2	6.5	MW-0 IN ORIGINAL JAR
2-LR1	Local Rock Sample	22	3'
2-M1	Marcellus Shale sample 1	9	BLACK, AMERICAN WASTE
2-M2	Marcellus Shale sample 2	12	BROWNISH,TALISMAN ENERGY
2-M3	Marcellus Shale sample 3	5	GREY,CHESAPEAKE ENERGY

Soil Sampling - Field Data Sheet

CoPhysics Corporation

Location: Herdman Road, Angelica, NY 14709

Date: 03/02/2010 **Time Arrived: 4:04 PM** **Time Departed: 5:15 PM**

Larry Shilling, Landfill District Manager \ Karen Flanders, EH&S Office # (585) 466-7271 Cell # (716) 560-7915
5 total samples

Radiation Bkg: 8 uR/hr Surface , Coordinates, Longitude 78° 17' 29" Latitude 42° 17' 29"

Manufacturer	Model	Serial	Probe Model / Serial	Cal. Date
Ludlum	12	83334	44-2 / 83334A	1/19/2010

Sample No.	Type	uR/hr	Depth
3-LS1	Local Soil 1	22	SURFACE TO 6'
3-W1	Well Cuttings 1	5.5	MW47A
3-W2	Well Cuttings 2	5.5	MW42A
3-LR1	Local Rock Sample 1	22	SURFACE TO 6 '
3-M1	Marcellus Shale sample 1	12	BLACK OILY, UNKOWN ORIGIN

EXHIBIT C

1.7.8 Flowback Water Handling On-Site

The Department proposes to require that operators storing flowback water on-site would be required to use watertight tanks located within secondary containment, and remove the fluid from the wellpad within specified time frames.

1.7.9 Flowback Water Disposal

Under existing regulations, before a permit is issued, the operator must disclose plans for disposal of flowback water and production brine. Further, in the SGEIS the Department proposes to use a new "Drilling and Production Waste Tracking" process, similar to the process applicable to medical waste, to monitor disposal. Under existing regulations, full analysis and approvals under state water laws and regulations are required before a water treatment facility can accept flowback from high-volume hydraulic fracturing operations. Appendix 22 includes a description and flow chart of the required approval process for discharge of flowback water or production brine from high-volume hydraulic fracturing to a Publicly-Owned Treatment Works (POTW). An applicant proposing discharge to a POTW would be required to submit a treatment capacity analysis for the receiving POTW, and, in the event that the POTW is the primary fluid disposal plan, a contingency plan. Additionally, limits would be established for NORM in POTW influent.

1.7.10 Management of Drill Cuttings

The Department has determined that drill cuttings are solid wastes, specifically construction and demolition debris, under the State's regulatory system. Therefore, the Department would allow disposal of cuttings from drilling processes which utilize only air and/or water on-site, at construction and demolition (C&D) debris landfills, or at municipal solid waste (MSW) landfills, while cuttings from processes which utilize any oil-based or polymer-based products could only be disposed of at MSW landfills. The revised draft SGEIS proposes to require, pursuant to permit conditions and/or regulation, that a closed-loop tank system be used instead of a reserve pit to manage drilling fluids and cuttings for:

- Horizontal drilling in the Marcellus Shale without an acceptable acid rock drainage (ARD) mitigation plan for on-site cuttings burial; and

- Cuttings that, because of the drilling fluid composition used must be disposed off-site, including at a landfill.

Only ARD mitigation plans that do not require long-term monitoring would be acceptable. Examples are provided in Chapter 7.

1.7.11 Emissions and Air Quality

The need to re-evaluate air quality impacts and the applicability of various regulations was raised during the scoping process, with emphasis on the duration of activities at a multi-well pad and the number of internal combustion engines used for high-volume hydraulic fracturing.

1.7.11.1 2009 Draft SGEIS

The following conclusions and requirements were set forth:

- Per United States Environmental Protection Agency (EPA) NESHAPS subpart ZZZZ, the compressor station would have an oxidation catalyst for formaldehyde. This also reduces carbon monoxide (CO) by 90% and Volatile Organic Compounds (VOCs) by 70%;
- Per EPA subpart HH, the glycol dehydrator would have a condenser to achieve a benzene emission of <1 ton per year (Tpy) (if "wet" gas is detected);
- Use of Ultra Low Sulfur Fuel (ULSF) of 15 parts per million (ppm) in all engines would be required;
- Small stack height increases on compressor, vent and dehydrator would be required (if "sour" and "wet" gas encountered for the latter two, respectively);
- All annual and short-term ambient standards (National Ambient Air Quality Standards, or NAAQS) and the Department's toxics thresholds (Annual and Short-Term Guideline Concentrations, or AGCs and SGCs) would be met, except 24-hour PM10/PM2.5 NAAQS due to drilling and hydraulic fracturing engines; and
- Impacts from a nearby pad modeled and indicated no overlap in the calculated "cumulative" impacts on local scale.

The facility definition for permitting was based on Clean Air Act (CAA) 112(n)(4) per EPA guidance at the time, which limits it to "surface area" (i.e., per pad). Annual emissions from all sources were calculated assuming ten wells per pad and resulted in a classification of the emissions as "minor" sources. No final determination was made as to whether non-road engines

shale shakers, desanders, desilters and centrifuges which separate the mud from the rock cuttings. The mud is then re-circulated back into the mud tanks where it is withdrawn by the mud pump for continued use in the well. As described in the 1992 GEIS, used drilling mud is typically reconditioned for use at a subsequent well. The subsequent well may be located on the same well pad or at another location.

Photo 5.16 - Drilling rig mud system (blue tanks)

5.2.4 Cuttings

The rock chips and very fine-grained rock fragments removed by the drilling process and returned to the surface in the drilling fluid are known as "cuttings" and are contained and managed either in a lined on-site reserve pit or in a closed-loop tank system.[149] As described in Section 5.13.1, the proper disposal method for cuttings is determined by the composition of the fluid or fluids used during drilling. The proper disposal method will also dictate how the cuttings must be contained on-site prior to disposal, as described by Section 7.1.9.

[149] Adapted from Alpha, 2009, p. 133.

5.2.4.1 Cuttings Volume

Horizontal drilling penetrates a greater linear distance of rock and therefore produces a larger volume of drill cuttings than does a well drilled vertically to the same depth below the ground surface. For example, a vertical well with surface, intermediate and production casing drilled to a total depth of 7,000 feet produces approximately 154 cubic yards of cuttings, while a horizontally drilled well with the same casing program to the same target depth with an example 4,000-foot lateral section produces a total volume of approximately 217 cubic yards of cuttings (i.e., about 40% more). A multi-well site would produce approximately that volume of cuttings from each well.

5.2.4.2 NORM in Marcellus Cuttings

To determine NORM concentrations and the potential for exposure to NORM contamination in Marcellus rock cuttings and cores (i.e., continuous rock samples, typically cylindrical, recovered during specialized drilling operations), the Department conducted field and sample surveys using portable Geiger counter and gamma ray spectroscopy methods. Gamma ray spectroscopy analyses were performed on composited Marcellus samples collected from two vertical wells drilled through the Marcellus, one in Lebanon (Madison County), and one in Bath (Steuben County). The results of these analyses are presented in Table 5.2a. Department staff also used a Geiger counter to screen three types of Marcellus samples: cores from the New York State Museum's collection in Albany; regional outcrops of the unit; and various Marcellus well sites from the west-central part of the state, where most of the vertical Marcellus wells in NYS are currently located. These screening data are presented in Table 5.2b. Additional radiological analytical data for Marcellus Shale drill cuttings has been reported from Marcellus wells in Pennsylvania. Samples were collected from loads of drill cuttings being transported for disposal, as well as directly from the drilling rigs during drilling of the horizontal legs of the wells. The materials sampled were screened in-situ with a micro R meter, and analyzed by gamma ray spectroscopy. These data are provided in Table 5.3. As discussed further in Chapter 6, the results, which indicate levels of radioactivity that are essentially equal to background values, do not indicate an exposure concern for workers or the general public associated with Marcellus cuttings.

Table 5.2 - 2009 Marcellus Radiological Data

Table 5.2a Marcellus Radiological Data from Gamma Ray Spectroscopy Analyses

Well (Depth)	API #	Date Collected	Town (County)	Parameter	Result +/- Uncertainty
Crouch C 4H (1040 feet - 1115 feet)	31-053-26305-00-00	3/17/09	Lebanon (Madison)	K-40	14.438 +/- 1.727 pCi/g
				Tl-208	0.197 +/- 0.069 pCi/g
				Pb-210	2.358 +/- 1.062 pCi/g
				Bi-212	0.853 +/- 0.114 pCi/g
				Bi-214	1.743 +/- 0.208 pCi/g
				Pb-214	1.879 +/- 0.170 pCi/g
				Ra-226	1.843 +/- 0.573 pCi/g
				Ac-228	0.850 +/- 0.169 pCi/g
				Th-234	1.021 +/- 0.412 pCi/g
				U-235	0.185 +/- 0.083 pCi/g
Blair 2A (2550' - 2610')	31-101-02698-01-00	3/26/09	Bath (Steuben)	K-40	22.845 +/- 2.248 pCi/g
				Tl-208	0.381 +/- 0.065 pCi/g
				Pb-210	0.535 +/- 0.712 pCi/g
				Bi-212	1.174 +/- 0.130 pCi/g
				Bi-214	0.779 +/- 0.120 pCi/g
				Pb-214	0.868 +/- 0.114 pCi/g
				Ra-226	0.872 +/- 0.330 pCi/g
				Ac-228	1.087 +/- 0.161 pCi/g
				Th-234	0.567 +/- 0.316 pCi/g
				U-235	0.079 +/- 0.058 pCi/g

Table 5.2b Marcellus Radiological Data from Geiger Counter Screening

Media Screened	Well	Date	Location (County)	Results
Cores	Beaver Meadow 1	3/12/09	NYS Museum (Albany)	0.005 - 0.080 mR/hr
	Oxford 1	3/12/09	NYS Museum (Albany)	0.005 - 0.065 mR/hr
	75 NY-14	3/12/09	NYS Museum (Albany)	0.015 - 0.065 mR/hr
	EGSP #4	3/12/09	NYS Museum (Albany)	0.005 - 0.045 mR/hr
	Jim Tiede	3/12/09	NYS Museum (Albany)	0.005 - 0.025 mR/hr
	75 NY-18	3/12/09	NYS Museum (Albany)	0.005 - 0.045 mR/hr
	75 NY-12	3/12/09	NYS Museum (Albany)	0.015 - 0.045 mR/hr
	75 NY-21	3/12/09	NYS Museum (Albany)	0.005 - 0.040 mR/hr
	75 NY-15	3/12/09	NYS Museum (Albany)	0.005 - 0.045 mR/hr
	Matejka	3/12/09	NYS Museum (Albany)	0.005 - 0.090 mR/hr
Outcrops	N/A	3/24/2009	Onesquethaw Creek (Albany)	0.02 - 0.04 mR/hr
	N/A	3/24/2009	DOT Garage, CR 2 (Albany)	0.01 - 0.04 mR/hr
	N/A	3/24/2009	SR 20, near SR 166 (Otsego)	0.01 - 0.04 mR/hr
	N/A	3/24/2009	Richfield Springs (Otsego)	0.01 - 0.06 mR/hr
	N/A	3/24/2009	SR 20 (Otsego)	0.01 - 0.03 mR/hr
	N/A	3/24/2009	Gulf Rd (Herkimer)	0.01 - 0.04 mR/hr
Well Sites	Beagell 2B	4/7/2009	Kirkwood (Broome)	0.04 mR/hr *
	Hulsebosch 1	4/2/2009	Elmira City (Chemung)	0.03 mR/hr *
	Bush S1	4/2/2009	Elmira (Chemung)	0.03 mR/hr *

	Parker 1	4/7/2009	Oxford (Chenango)	0.05 mR/hr *
Well Sites	Donovan Farms 2	3/30/2009	West Sparta (Livingston)	0.03 mR/hr *
	Fee 1	3/30/2009	Sparta (Livingston)	0.02 mR/hr *
	Meter 1	3/30/2009	West Sparta (Livingston)	0.03 mR/hr *
	Schiavone 2	4/6/2009	Reading (Schuyler)	0.05 mR/hr *
	WGI 10	4/6/2009	Dix (Schuyler)	0.07 mR/hr *
	WGI 11	4/6/2009	Dix (Schuyler)	0.07 mR/hr *
	Calabro T1	3/26/2009	Orange (Schuyler)	0.03 mR/hr *
	Calabro T2	3/26/2009	Orange (Schuyler)	0.05 mR/hr *
	Frost 2A	3/26/2009	Orange (Schuyler)	0.05 mR/hr *
	Webster T1	3/26/2009	Orange (Schuyler)	0.05 mR/hr *
	Haines 1	4/1/2009	Avoca (Steuben)	0.03 mR/hr *
	Haines 2	4/1/2009	Avoca (Steuben)	0.03 mR/hr *
	McDaniels 1A	4/1/2009	Urbana (Steuben)	0.03 mR/hr *
	Drumm G2	4/1/2009	Bradford (Steuben)	0.07 mR/hr *
	Hemley G2	3/26/2009	Hornby (Steuben)	0.03 mR/hr *
	Lancaster M1	3/26/2009	Hornby (Steuben)	0.03 mR/hr *
	Maxwell 1C	4/2/2009	Caton (Steuben)	0.07 mR/hr *
	Scudder 1	3/26/2009	Bath (Steuben)	0.03 mR/hr *
	Blair 2A	3/26/2009	Bath (Steuben)	0.03 mR/hr *
	Retherford 1	4/1/2009	Troupsburg (Steuben)	0.05 mR/hr *
	Carpenter 1	4/1/2009	Troupsburg (Steuben)	0.05 mR/hr *
	Cook 1	4/1/2009	Troupsburg (Steuben)	0.05 mR/hr *
	Zinck 1	4/1/2009	Woodhull (Steuben)	0.07 mR/hr *
	Tiffany 1	4/7/2009	Owego (Tioga)	0.03 mR/hr *
*maximum values detected				

Table 5.3 - Gamma Ray Spectroscopy

LAB	Sample#	Date	Sample Location	Material Type	Depth	Gamma*	Radionuclide Concentration (per wet mass) Radium-226			Thorium-232			Potassium-40		
ID#		Collected			(feet)	(uR/hr)	(pCi/g)			(pCi/g)			(pCi/g)		
Gas Drill Rig Cuttings															
738-1	31110A	3/11/2010	Bradford Co., Pa.	Marcellus shale	5942	8 / 10	2.4	±	0.2	0.8	±	0.1	12.9	±	1.0
738-2	31110B	3/11/2010	Bradford Co., Pa.	Hamilton Limestone	6362	5 / 5 **	1.1	±	0.1	0.9	±	0.1	17.8	±	1.0
738-3	31110C	3/11/2010	Bradford Co., Pa.	Marcellus shale	6587	11 / 8	4.3	±	0.2	0.9	±	0.1	15.8	±	0.9
738-5	31910A	3/19/2010	Tioga County, Pa.	Marcellus shale	6101	5 / 10	2.8	±	0.2	0.9	±	0.1	17.4	±	1.0
738-6	31910B	3/19/2010	Tioga County, Pa.	Marc. shale with Baryte	6101	5 / 10	0.6	±	0.1	0.2	±	0.0	2.4	±	0.2
738-13	1-M1	3/2/2010	Landfill, Lawman, NY	transported gas rig cuttings	unk.	12	2.3	±	0.1	0.7	±	0.1	17.2	±	1.1
738-11	2-M2	3/2/2010	Landfill, Painted Post, NY	transported gas rig cuttings	unk.	12	0.9	±	0.1	1.2	±	0.1	16.7	±	1.1
738-12	3-M1	3/2/2010	Landfill, Angelica, NY	transported gas rig cuttings	unk.	12	2.7	±	0.2	0.8	±	0.1	12.6	±	0.8
						AVERAGE	2.1	±	1.2	0.7	±	0.3	14.2	±	4.6

Table 5.27 - Summary of Characteristics of On-Site Flowback Water Treatment Technologies (Updated July 2011)[261]

Characteristic	Filtration	Ion Exchange	Reverse Osmosis	EDR	Thermal Distillation	Ozone / Ultrasonic / Ultraviolet
Energy Cost	Low	Low	Moderate	High	High	Low
Energy Usage vs. TDS	N/A	Low	Increase	High Increase	Independent	Increase
Applicable to	All Water types	All Water types	Moderate TDS	High TDS	High TDS	All Water types
Plant / Unit size	Small / Modular	Small / Modular	Modular	Modular	Large	Small / Modular
Microbiological Fouling	Possible	Possible	Possible	Low	N/A	Possible
Complexity of Technology	Low	Low	Moderate / High Maintenance	Regular Maintenance	Complex	Low
Scaling Potential	Low	Low	High	Low	Low	Low
Theoretical TDS Feed Limit (mg/L)	N/A	N/A	32,000	40,000	100,000+	Depends on turbidity
Pretreatment Requirement	N/A	Filtration	Extensive	Filtration	Minimal	Filtration
Final Water TDS	No impact	200-500 ppm	200-500 ppm	200-1000 ppm	< 10 mg/L	Variable
Recovery Rate (Feed TDS >20,000 mg/L)	N/A	N/A	30-50%	60-80%	75-85%	Variable

5.13 Waste Disposal

5.13.1 Cuttings from Mud Drilling

The 1992 GEIS discusses on-site burial of cuttings generated during compressed air drilling. This option is also viable for cuttings generated during drilling with fresh water as the drilling fluid. However, cuttings that are generated during drilling with polymer- or oil-based muds are considered industrial non-hazardous waste and therefore must be removed from the site by a permitted Part 364 Waste Transporter and properly disposed in a solid waste landfill. In New York State the NORM in cuttings is not precluded by regulation from disposal in a solid waste

[261] URS, 2011, p. 5-9

landfill, though well operators should consult with the operators of any landfills they are considering using for disposal regarding the acceptance of Marcellus Shale drill cuttings by that facility.

5.13.2 Reserve Pit Liner from Mud Drilling

The 1992 GEIS discusses on-site burial, with the landowner's permission, of the plastic liner used for the reserve pit for air-drilled wells. This option is also viable for wells where fresh-water is the drilling fluid. However, pit liners for reserve pits where polymer- or oil-based drilling muds are used must be removed from the site by a permitted Part 364 Waste Transporter and properly disposed in a solid waste landfill.

5.13.3 Flowback Water

As discussed in Section 5.12, options exist or are being developed for treatment, recycling and reuse of flowback water. Nevertheless, proper disposal is required for flowback water that is not reused. Factors which could result in a need for disposal instead of reuse include lack of reuse opportunity (i.e., no other wells being fractured within reasonable time frames or a reasonable distance), prohibitively high contaminant concentrations which render the water untreatable to usable quality, or unavailability or infeasibility of treatment options for other reasons.

Flowback water requiring disposal is considered industrial wastewater, like many other water-use byproducts. The Department has an EPA-approved program for the control of wastewater discharges. Under New York State law, the program is called the State Pollutant Discharge Elimination System (SPDES). The program controls point source discharges to ground waters and surface waters. SPDES permits are issued to wastewater dischargers, including POTWs, and include specific discharge limitations and monitoring requirements. The effluent limitations are the maximum allowable concentrations or ranges for various physical, chemical, and/or biological parameters to ensure that there are no impacts to the receiving water body.

6.1.9 Solids Disposal

Most waste generated at a well site is in liquid form. Rock cuttings and the reserve pit liner are the significant exception. The 1992 GEIS describes potential adverse impacts to agricultural operations if materials are buried at too shallow a depth or work their way back up to the surface. Concerns unique to Marcellus development and multi-well pad drilling are discussed below.

6.1.9.1 NORM Considerations - Cuttings

Gamma ray logs from deep wells drilled in New York over the past several decades show the Marcellus Shale to be higher in radioactivity than other bedrock formations including other potential reservoirs that could be developed by high-volume hydraulic fracturing. However, based on the analytical results from field-screening and gamma ray spectroscopy performed on samples of Marcellus Shale, NORM levels in cuttings are not likely to pose a problem because – as set forth in Section 5.2.4.2 – the levels are similar to those naturally encountered in the surrounding environment.

6.1.9.2 Cuttings Volume

As explained in Chapter 5, the total volume of drill cuttings produced from drilling a horizontal well may be about 40% greater than that for a conventional, vertical well to the same target depth. For multi-well pads, cuttings volume would be multiplied by the number of wells on the pad. The potential water resources impact associated with the greater volume of drill cuttings from multiple horizontal well drilling operations would arise from the retention of cuttings during drilling, necessitating a larger reserve pit that may be present for a longer period of time, unless the cuttings are directed into tanks as part of a closed-loop tank system. The geotechnical stability and bearing capacity of buried cuttings, if left in a common pit, may need to be reviewed prior to pit closure.[304]

6.1.9.3 Cuttings and Liner Associated With Mud-Drilling

Operators have not proposed on-site burial of mud-drilled cuttings, which would be equivalent to burial or direct ground discharge of the drilling mud itself. Contaminants in the mud or in contact with the liner if buried on-site could adversely impact soil or leach into shallow groundwater.

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[304] Alpha, 2009, p. 6-7.

6.7 Naturally Occurring Radioactive Materials in the Marcellus Shale

Chapter 4 explains that the Marcellus Shale is known to contain NORM concentrations at higher levels than surrounding rock formations, and Chapter 5 provides some sample data from Marcellus Shale cuttings. Activities that have the potential to concentrate these constituents through surface handling and disposal may need regulatory oversight to ensure adequate protection of workers, the general public, and the environment. Gas wells can bring NORM to the surface in the cuttings, flowback fluid and production brine, and NORM can accumulate in pipes and tanks (pipe scale and sludge.) Based upon currently available information it is anticipated that flowback water will not contain levels of NORM of significance, whereas production brine is known to contain elevated NORM levels. Radium-226 is the primary radionuclide of concern from the Marcellus.

Elevated levels of NORM in production brine (measured in picocuries/liter or pCi/L) may result in the buildup of pipe scale containing elevated levels of radium (measured in pCi/g). The amount and concentration of radium in the pipe scale would depend on many conditions, including pressures and temperatures of operation, amount of available radium in the formation, chemical properties, etc. Because the concentration of radium in the pipe scale cannot be measured without removing or disconnecting the pipe, a surrogate method is employed, conducting a radiation survey of the pipe exterior. A high concentration of radium in the scale would result in an elevated radiation exposure level at the pipe's exterior surface (measured in mR/hr) and can be detected with a commonly used survey instrument. The Department of Health would require a radioactive materials license when the radiation exposure levels of accessible piping and equipment are greater than 50 microR/hr (μR/hr). Equipment that exhibits dose rates in excess of this level will be considered to contain processed and concentrated NORM for the purpose of waste determinations.

Oil and gas NORM occurs in both liquid (production brine), solid (pipe scale, cuttings, tank and pit sludges), and gaseous states (produced gas). Although the highest concentrations of NORM are in production brine, it does not present a risk to workers because the external radiation levels are very low. However, the build-up of NORM in pipes and equipment (pipe scale and sludge) has the potential to expose workers handling (cleaning or maintenance) the pipe to increased radiation levels. Also wastes from the treatment of production brines may contain concentrated

NORM and therefore may require controls to limit radiation exposure to workers handling this material as well as to ensure that this material is disposed of in accordance with 6 NYCRR § 380.4.

Radium is the most significant radionuclide contributing to oil and gas NORM. It is fairly soluble in saline water and has a long radioactive half life - about 1,600 years (Table 6.30). Radon gas, which under most circumstances is the main human health concern from NORM, is produced by the decay of radium-226, which occurs in the uranium-238 decay chain. Uranium and thorium, which are naturally occurring parent materials for radium, are contained in mineral phases in the reservoir rock cuttings, but have very low solubility. The very low concentrations and poor water solubility are such that uranium and thorium pose little potential health threat.

Table 6.30 - Radionuclide Half-Lives

Radionuclide	Half-life	Mode of Decay
Ra-226	1,600 years	alpha
Rn-222	3.824 days	alpha
Pb-210	22.30 years	beta
Po-210	138.40 days	alpha
Ra-228	5.75 years	beta
Th-228	1.92 years	alpha
Ra-224	3.66 days	alpha

In addition to exploration and production (E&P) worker protection from NORM exposure, the disposal of NORM-contaminated E&P wastes is a major component of the oil and gas NORM issue. This has attracted considerable attention because of the large volumes of production brine (>109 billion bbl/yr; API estimate) and the high costs and regulatory burden of the main disposal options, which are underground injection in Class II UIC wells and offsite treatment. The Environmental Sciences Division of Argonne National Laboratory has addressed E&P NORM disposal options in detail and maintains a Drilling Waste Management Information System website that links to regulatory agencies in all oil and gas producing states, as well as providing detailed technical information.

In NYS the disposal of processed and concentrated NORM in the form of pipe scale or water treatment waste is subject to regulation under Part 380. Because disposal of Part 380 regulated waste is prohibited in Part 360 regulated solid waste landfills, this waste would require disposal in out-of-state facilities approved to accept NORM wastes. Disposal facilities that can accept this type of waste include select RCRA C facilities and low-level radioactive waste disposal sites.

6.8 Socioeconomic Impacts[401]

This section provides a discussion of the potential socioeconomic impacts on the Economy, Employment, and Income (Section 6.8.1); Population (Section 6.8.2); Housing (Section 6.8.3); Government Revenues and Expenditures (Section 6.8.4); and Environmental Justice (Section 6.8.5). A more detailed discussion of the potential impacts, as well as the assumptions used to estimate the impacts, is provided in the Economic Assessment Report, which is available as an addendum to this SGEIS.

To estimate the socioeconomic impacts associated with the use of high-volume hydraulic fracturing techniques for extracting natural gas, several assumptions must be made about the amount of natural gas development that would occur, the expected rate of development, the length of time over which that development would occur, and the distribution of this development throughout the state.

For the purposes of this SGEIS, the expected rate of development is measured by the number of wells constructed annually. Two different levels of development are analyzed – a low development scenario, and an average development scenario. These development scenarios were developed by the Department based on information the Department had requested from the Independent Oil & Gas Association of New York (IOGA-NY). IOGA-NY started with an estimated average rate of development based on the following assumptions:

[401] Section 6.8, in its entirety, was provided by Ecology and Environment Engineering, P.C., August 2011, and was adapted by the Department.

The Department proposes to require, via permit condition, the following additional requirements:

- Gas vented through the flare stack would be ignited whenever possible. The stack would be equipped with a self-ignition device; and
- A reduced emissions completion, with minimal flaring (if any), would be performed whenever a sales line is available during completion at any individual well or the multi-well pad.

7.7 Mitigating NORM Impacts

7.7.1 State and Federal Responses to Oil and Gas NORM[502]

Discovery of elevated concentrations of NORM levels in other areas outside of New York in the 1980s led to a series of state and private investigations of the issue. State responses to the potential of elevated oil and gas NORM range from no action (barring self-reported problems) to decisions for further study, to implementation of new formal regulations and guidance documents. NORM is not subject to direct federal regulation (except its transport) under either the AEA or LLRWPA, and exploration and production (E&P) wastes are specifically exempt from regulation under Subtitles D and C of RCRA (LA Office of Conservation, 2009); however, NORM is regulated indirectly at the federal level through potential environmental impacts to drinking water (SDWA) and cleanup of abandoned hazardous waste sites (CERCLA and NCP).

7.7.2 Regulation of NORM in New York State

In New York State, the handling of radioactive material and waste is regulated. Requirements for radioactive materials licensing, excluding medical and educational uses in New York City and entities under exclusive federal jurisdiction, are in the State Sanitary Code, Chapter 1, Part 16 (10 NYCRR 16) and Industrial Code Rule 38 (12 NYCRR 38). The NYSDOH is the licensing agency, and it enforces both Part 16 and Code Rule 38. Requirements for environmental discharges, waste shipment and disposal, or environmental cleanup are regulated by the Department under its 6 NYCRR Part 380 series of regulations. Additionally, the Department's solid waste disposal regulations, Part 360, precludes disposal of wastes regulated under Part 380 in a Part 360 solid waste landfill.

[502] Alpha, 2009, p. 2-44 et seq.

Disposal of flowback waster or brine through a POTW is addressed in section 7.1.8.1.

The overall licensing requirement for radioactive material, §16.100 of the State Sanitary code states, in part, that "no person shall transfer, receive, possess or use any radioactive material except pursuant to a specific or general license issued under this Part." Exemptions to the overall requirement are listed in Part 16, Appendix 16-A. In summary, any person is exempt from the requirements to the extent that such person transfers, receives, possesses or uses products or materials containing radioactive material in concentrations and quantities not in excess of those listed in the accompanying tables. Where multiple radionuclides are present, the sum of the ratios shall not exceed unity (one).

The discharge of licensed radioactive material and processed and concentrated NORM (such as waste filters, sludges, or backwash from the treatment of flowback water or production brine) into the environment is regulated by the Department. NORM contained in flowback water or production brine may be subject to applicable SPDES permit conditions.

Analytical results from initial sampling of production brine from vertical gas production wells in the Marcellus formation have been reviewed and suggest that the potential for NORM scale buildup in pipes and equipment may require licensing of a facility. The results also indicate that production brine may be subject to discharge limitations to ensure compliance with Part 380.

Existing data from drilling in the Marcellus Formation in other States, and from within New York for wells that were not hydraulically fractured, shows significant variability in NORM content. This variability appears to occur both between wells in different portions of the formation and at a given well over time. This makes it important that samples from wells in different locations within New York State are used to assess the extent of this variability. During the initial Marcellus development efforts, sampling and analysis would be undertaken in order to assess this variability. These data would be used to determine whether additional mitigation is necessary to adequately protect workers, the general public, and environment of the State of New York.

In order to determine which gas production facilities may be subject to the licensing and environmental discharge requirements, radiological surveys and measurements are necessary

including radiation exposure rate measurements of areas of potential NORM contamination, accessible piping, tanks or other equipment that could contain NORM pipe scale buildup. Facilities that possess NORM wastes or piping, tanks or other equipment with elevated radiation levels may need a radioactive materials license. Further, any discharge of effluents into the environment would need to be tested for NORM concentrations in order to ensure compliance with regulatory requirements.

The Department proposes to require, via permit condition and/or regulation, that radiation surveys be conducted at specified time intervals for Marcellus wells developed by high-volume hydraulic fracturing completion methods on all accessible well piping, tanks, or other equipment that could contain NORM scale buildup. The surveys would be required to be conducted for as long as the facility remains in active use. Once taken out of use no increases in dose rate are to be expected. Therefore, surveys may stop until either the site again becomes active or equipment is planned to be removed from the site. If equipment is to be removed, radiation surveys would be performed to ensure appropriate disposal of the pipes and equipment. All surveys would be conducted in accordance with NYSDOH protocols. The NYSDOH's Radiation Survey Guidelines and a sample Radioactive Materials Handling License are presented in Appendix 27.

The Department finds that existing regulations, in conjunction with the proposed requirements for radiation surveys, would reduce any potential significant impacts from NORM.

7.8 Socioeconomic Mitigation Measures[503]

High-volume hydraulic fracturing operations would have many positive socioeconomic results in the local areas where development is expected to occur. These operations would likely result in a substantial increase in economic activity in the affected areas, as well as a substantial increase in tax revenues to the state and localities. However, as described in previous sections, this increased economic activity would also have the potential to result in adverse impacts in regions with high drilling activity, particularly acute in the short term, including localized impacts on the housing market caused by the in-migration of construction and production workforces and an

[503] Section 7.8, in its entirety, was provided by Ecology and Environment Engineering, P.C., August 2011 and was adapted by the Department.

by NYSDOH-licensed operators, or the impacted equipment and pipes could be sent out-of-state for cleaning or disposal at facilities regulated for those purposes.

The Department also recognizes that the literature on the subject of expected dose rates is not in full agreement. Although NYSDOH does not expect that all wells will exhibit significant TENORM scale buildup, if data were to show that the majority of wells exhibited evidence of such buildup, NYSDOH would consider the appropriateness of a blanket licensing system. The SGEIS provides a description of the proposed licensing criteria, and also contains an explanation with respect to NYSDOH's requirements and implementation process.

As described in the Response to Comment on Health Risks, natural gas can also contain radon, a potential indoor air contaminant. A screening analysis presented in the NYSDOH Public Health Review suggests that radon exposure levels from Marcellus Shale natural gas could contribute a small fraction to the overall indoor radon levels. There is substantial uncertainty regarding radon levels in shale gas from various geographic locations and formations because of limited monitoring data, especially from the Appalachian Basin, which includes the Marcellus Shale. However, the NYSDOH Public Health Review used EPA data that bounded the highest levels seen in the Marcellus Shale to date, and based on that data, the Department does not expect that there would be any significant radon impacts to end users.

With respect to radon in cuttings and attendant potential risks to workers, or others, from landfills accepting cuttings, the Department does not believe that radon emanation from a landfill would pose a significant risk for the following reasons: (1) the relatively low concentrations of radium in cuttings; (2) concentration limits already incorporated into Part 360 permits for New York landfills accepting Marcellus Shale cuttings; (3) the robust design of solid waste landfills in New York; and (4) the rapid dispersal of any Rn gas reaching the surface of a landfill. In addition, studies completed by the U.S. Department of Energy's (DOE) Argonne National Laboratory support this assessment. Limiting a landfill waste mass to an average concentration of 50 picocuries/gram would keep worker exposure below the regulatory limit of 100 mrem/year. As a conservative measure, New York landfill permits are more stringent by halving this average concentration limit to 25 picocuries/gram. In addition, New York's solid waste landfills are required to be more robust in design than those modeled by DOE. These landfills must install a

radiation portal monitor at their weigh stations, maintain a Department approved training program, have an equipment calibration procedure, establish a relationship between radiation monitor readings and radium concentrations in loads of cuttings, set their monitor alarm level well below the allowed concentration, and notify the Department whenever the alarm is set off to ensure adequate evaluation of the cause of that alarm.

Similarly, impacts to POTW operators and their workers from the potential buildup of NORM in sludge produced at these plants would be reduced by the influent concentration limit proposed the SGEIS for facility SPDES permits of 15 picocuries/liter of radium, which is one quarter of the 6 NYCRR Part 380 discharge criteria for radium. The criteria in Part 380 were developed based on several factors, including possible downstream impacts to drinking water sources. By severely limiting the potential for radium buildup in plant sludge, risks to workers due to the generation of radon would be significantly reduced.

The Department acknowledges the commenters concerns for the proposed generation of preferential pathway for Rn infiltration into structures by the fracturing of the Marcellus formation and the failure of casings for wells located near structures. However, due to the short half-life of Rn (3.8 days) and relatively slow transmission rate of gasses through rock and soil, gas migration into a building through postulated preferential pathways would generate no measurable increase in Rn levels above background levels. Radon infiltrates basements from rock and soils in the vicinity of a structure. Even if such pathways for Rn transmission were present, risks of infiltration from the much higher concentration of natural gas would pose a much more significant and immediate risk than the relatively low concentrations of radon.

The Department has also considered and evaluated potential risks posed by the NORM content of Marcellus Shale brine and recognizes the need to require adequate management and control measures, including discharge and disposal criteria to protect public health and the environment. Production brine and much of the flowback could contain NORM in excess of drinking water standards and therefore would need to be properly regulated to protect water supplies. To reduce these impacts the Department considered requiring tanks for on-site storage for all flowback and brine. There would also be time limits for on-site storage, which would limit the accumulation of waste at a given site. The Department further considered imposing testing requirements prior

EXHIBIT D

From a regulatory perspective, there are no Part 360 requirements that benches need to be used to help ensure stability, facilitate construction, control erosion, or other related issues.

These issues are regulated by requiring that the engineer consider the slope's effect on the subgrade and overlying double-liner system as well as the landfills final cover system to ensure that they are stable. This has been done in this case.

The aforementioned engineering calculations demonstrate overall stability of the subgrade, liner, and final cover system. They appropriately used the actual slopes and topography depicted on drawing sheets 6 and 8 and demonstrate that there is no need for benches in these slopes to ensure stability. The designs exceed the applicable required minimum factors of safety using the standard practice for evaluating slope stability.

Radiation Section I – Comments from the Residents for the Protection of Lowman and Chemung (R1-R13)

Please note: most of the questions related to radiation can be answered by review of the "draft generic EIS and final supplemental generic EIS on the Oil, Gas and Solution Mining Regulatory Program for Horizontal Fracturing to Develop the Marcellus Shale and Other Low-Permeability Gas Reservoirs" (http://www.dec.ny.gov/energy/75370.html#2015).

Comment #R1: 1. Introduction: It is unlikely the applicant can obtain a variance because, as discussed below, it will be unable to show that increased volumes of radioactive leachate the landfill generates can be managed without significant adverse impacts on the groundwater beneath onsite leachate storage ones to the Chemung River. The river is hydrologically connect to the principal aquifer beneath the expansion area. In addition, the river receives all of the landfill's leachate without removing any of its radioactivity.

Response #R1. *This and other introductory statements are addressed in the responses to radiation related comments, aquifer related comments, and hydrogeological comments.*

Comment #R2: Several of the concerns outlined above regarding the risky hydrogeological setting of the expansion site and the deficiencies in design from the standpoint of safety are relevant to assessing the nature of the risk of accepting low-level radioactive waste from Pennsylvania oil and gas shale drilling-related sources. These risks have not been adequately considered.

Response #R2: *Low-level radioactive waste is not accepted at the landfill. The commenter incorrectly characterizes drill cuttings as low-level radioactive waste. Drill cuttings are rock and soil residue from the boring of a well. These materials can contain small amounts of naturally-occurring radioactive material (NORM). Waste containing NORM, however, is not considered regulated radioactive waste and may be disposed of in municipal solid waste landfills such as the Chemung County Landfill. In the Matter of Chemung County, 2011 WL 6934245, at * 3 (Aug. 4, 2011). Other wastes from gas drilling operations (such as equipment and piping which contains*

pipe scale; residues from the treatment or processing of flowback water, production brine, or other drilling or production wastes; and bulk liquids of any kind) are not accepted at the Chemung County Landfill or any other landfill in the State.

Comment #R3: However, a basis for considering such risks is available now that was not available at the time of the applicant's 2010 application for a permit modification. As Dr. Resnikoff notes, in the time that has elapsed since the 2010 review, radium concentrations in the landfill's leachate have exceeded 14 pCi per liter, substantially higher than background for the region–and substantially higher than the concentration of radioactivity in rock cuttings reported by the applicant;

Response #R3: *First, the commenter has improperly compared radium concentrations in shale/rock cuttings to those in leachate. They are two distinctly different matrices. Second, Department staff performed confirmatory analyses of NORM in drill cuttings and determined that these values were similar to those reported by the applicant. Lastly, it appears that Dr. Resnikoff, to obtain his 14.18 pCi per liter value, improperly added the concentrations of radium 226 and 228. In this case, concentrations of these isotopes are not additive. They should be reviewed as stand-alone numbers.*

Comment #R4: The leachate is stored onsite in surface impoundments, or open air ponds; and the leachate is periodically pumped from the ponds and transported to the Elmira publicly-owned treatment works (POTW), which is unable to remove any radioactivity from the leachate before treating it and discharging it directly to the Chemung River. Because the landfill's leachate has become contaminated with elevated radioactivity, it cannot be accurate, as the County states in the FEIS, that "the portal radiation monitoring system is sufficiently sensitive to detect waste loads containing [radiologically] elevated concentration waste materials and prevent their disposal in the landfill."

As reflected in public comments on the expansion proposal, the prospect of long-term, bioaccumulative pollution of both groundwater and the river is a substantial public concern. Accordingly, the Department should consider the basis for these concerns on their merits.

In 2014 alone, the landfill sent over 4 million gallons of radiologically contaminated leachate to the Elmira POTW. Because of its bioaccumulative properties, and its tendency to bind to sediments in water bodies, continued discharge of such volumes of leachate can be anticipated to degrade the quality of the river and its biota, including fish caught for consumption.

Response #R4: *Using Part 380 sewer and surface water discharge standards for radium as a reference point, Department staff have determined that leachate from the Chemung County Landfill, which is all sent to the Elmira Wastewater Treatment Facilities, does not present a significant threat to human health or the environment. According to values in the tables in 6 NYCRR Subpart 380-11.7, concentrations of radium that may be discharged without having to perform additional calculations or modeling to show compliance with public exposure standards are: 60 pCi/L for surface waters and 600 pCi/L for sewers. Part 380 table values were developed with consideration for potential of accumulation of radioactivity concentrations in biota. Please note, as stated above, these standards are only used a reference point. They do not apply to*

leachate from the Chemung County Landfill. That said, this leachate is tested semi-annually for radioactive constituents by a third-party ELAP-certified laboratory. These tests indicate that the concentration of radium 226 in leachate from the Chemung County Landfill ranges from 0.7 to 9.4 pCi/L. These concentrations are significantly lower than both Part 380 values described above.

The Department has reviewed leachate data to date and has not observed any upward trend in leachate as alleged by the commenter. Fluctuations in activity-concentrations have been observed and are to be expected. The Department will continue to monitor all analytical results.

Because the leachate values do not indicate increasing trends, and are one to two orders of magnitude lower than Part 380 discharge standards, it is considered protective of water quality to send the leachate to the WWTF.

Comment #R5: In addition, the low level of Radium in the landfill's leachate, in conjunction with the large volume of leachate sent to the Elmira publicly owned treatment works (POTW), presents a risk of harmful exposure to workers in the confined spaces inside the POTW.

Response #R5: *Please see the response to #R4.*

Comment #R6: In addition, the landfill's current permit provides that "industrial wastes" may not disposed in the landfill "which are incompatible with municipal waste, as determined by the Department." This provision authorizes the Department to direct the applicant to stop accepting such wastes upon a finding that they are incompatible with the proper treatment of the landfill's leachate. Because radioactive components found in the leachate are not treated before being discharged to the Chemung River like other components of the leachate, the Department may determine that disposal of deep shale drilling waste is incompatible with municipal waste because it renders the leachate generated by such waste unmanageable. That is, the radioactivity found in deep shale drilling waste is contaminating the leachate of the entire landfill, making its management through a POTW untenable.

Response #R6: *Please see the response to #R2 and #R4 above.*

Comment #R7: In addition, the storage of radioactive landfill leachate onsite for long periods of time threatens the principle aquifer beneath portions of the expansion area and in close proximity to the aquifer in other portions of the expansion area. The Department has designated principle aquifers as sensitive environments. 6 NYCRR § 360-1.2(a)(150). As noted above, the concentration of radium in leachate stored on the ground on site has exceeded the groundwater standard for releases to groundwater of radium. See 6 NYCRR § 703.5 (Ra-226, 3 pCi/L; total radium, 5 pCi/L).

Response #R7: *The Chemung County Landfill, including its leachate storage locations, is not over a primary aquifer. For further discussion of this topic, please refer to the aquifer response section.*

The regulation (6 NYCRR § 703.5) the commenter cites is not applicable as it is not a discharge standard. As stated above, leachate from the landfill is sent to the Elmira wastewater treatment facility (WWTF). It is not discharged directly to surface water or groundwater. Also, the levels of radium in leachate from the landfill are well below both the sewer and surface water discharge values for radium presented in 6 NYCRR Subpart 380-11.5, which again are only used here as a reference point.

Prior to being sent to the WWTF, leachate is stored in a double lined leachate impoundment which was specifically designed in conformance with Part 360 regulations to prevent leachate from entering the groundwater or surface water. The secondary liner of the impoundment acts as a leak detection system so that any potential leaks in the primary liner can be identified. Furthermore, there are groundwater monitoring wells down gradient of the impoundment.

Please refer to the responses to Resnickoff's comments below for more details.

Comment #R8: (intentionally left blank due to renumbering)

Comment #R9: Since the significance of such threats was not considered in the FEIS, (see below), the Department should obtain the information necessary to address this concern. To do so, the Department may direct the applicant to prepare a supplemental EIS on the subject. See 6 NYCRR 624.4(c)(6)(ii)(b).

Response #R9: *Chemung County prepared the SEQR record. The County's SEQR review is not within the purview of this Department action.*

Comment #R10: Even without an SEIS, the applicant should be required to submit an antidegradation analysis showing how water quality in the Chemung River will not be degraded by the discharge of millions of gallons of radium-contaminated leachate into the river. According to the Department's Antidegradation Policy, O&D Memo 85-40 (September 9, 1985), at 2:

Water quality based effluent limitations derived for SPDES permits provide for the protection and maintenance of attained higher uses above those included in standards currently assigned to waters receiving the effluent discharge. Variations in numerical water quality criteria that are not significant and do not interfere with the attained higher use are permitted.

Discharges of large volumes of wastewater contaminated with low levels of Radium "interfere with the attained higher use" of the reach of Chemung River immediately downstream from the Elmira POTW, which is fish propagation. The most recent biological assessment (macroinvertebrate) of the reach of the river downstream from the Elmira POTW was conducted in 2002. Without additional information, therefore, the Department has no basis for assessing the consequences of additional periodic discharges of low levels of radioactivity to the river.

Chemung County, acting as SEQRA lead agency, omitted from its SEQRA review consideration of the significance of impacts of low levels of radioactivity in the large volume of drilling wastes disposed in the landfill, despite acknowledging that these wastes are characterized by

radioactivity levels several times higher than background concentrations, and radioactivity detected in landfill's leachate has exceeded the level of radioactivity detected in drilling wastes disposed in the landfill.

Response #R10: *An anti-degradation analysis is not required. Department staff, after using Part 380 discharge standards as a reference point, determined that discharge limits, monitoring, and modelling (such as an anti-degradation analysis) were not necessary.*

Again, the Department was not the lead agency for the SEQR review and, as a result, SEQR comments are not applicable to this permitting action.

Comment #R11: In addition to waste accepted for immediate disposal, the landfill utilizes several waste streams as landfill cover material, under a beneficial use determination (BUD), from Pennsylvania. These materials should be presumed to be generated from drilling sites or their ancillary facilities, including contaminated soil, de-watered sludge, filter cake, and solidification pit remnants. In 2014, these four waste streams amounted to over 11,000 tons of materials stockpiled and ultimately disposed in the landfill. The Department should ask the applicant to identify all BUD materials associated with the oil and gas drilling industry. See 6 NYCRR § 360-1.15(d)(1)(iv)(a)(1). "Periodic testing" of such waste is required, (6 NYCRR §360-1.15(d)(1)(iv)(a)(2)), as is acceptable "procedures for run-on and run-off control of the storage areas for the solid waste". 6 NYCRR § 360-1.15(d)(1)(iv)(a)(5). If analysis of any BUD materials show there is more than a "little potential" for adverse impacts not found at the time of the initial BUD determination, the Department should revoke the determination for that waste stream. 6 NYCRR §§ 360-1.15(d)(3), (4). Since, as contended below, it is the mass of landfilled drilling wastes rather than their radioactive concentration that likely accounts for the elevated radioactivity level in the landfill's leachate, increasing the volume of such wastes represents a change in permit conditions than can be expected to result in specific significant adverse environmental impacts, discussed below. Since the elevated concentration of radioactivity in the landfill's leachate is new information, not available during the Department's 2010 review of the consequences of accepting deep shale drilling waste streams, the significance of the threats posed by managing the leachate and its potential effects to sensitive environments, (6 NYCRR § 360-1.2(a)(150)), has not previously been addressed.

Response #R11: *The Department has not approved materials related to the oil and gas industry to be used at the Chemung County Landfill as BUD. Nevertheless, all waste loads, including BUD materials, pass through the radiation detectors to ensure no materials above acceptable limits are placed in the landfill.*

Comment #R12: Despite rejecting the public's urging that it take a hard look at the consequences of continued acceptance of radioactive drilling-related waste streams, as Dr. Resnikoff notes in his memorandum, without any evidence the County in its FEIS asserts that Ra-226 is not soluble in water and thus should not be expected to be found in elevated concentrations in wet shale drilling-related wastes. The contrary is true: based on relevant research, the potentially substantial liquid component in the wastes has concentrations of radioactivity thousands of time higher than background, much higher than Marcellus Shale rock cuttings, desiccated and analyzed in a

laboratory. The landfill's current Part 360 permit allows wastes with as much as 80% liquid component to be deemed "solid waste" and thus disposed in the landfill.

Response #R12: *The commenter appears to have confused drill cuttings with other waste streams which have the potential to contain significantly elevated NORM concentrations such as brine from high-volume fracturing. Although the landfill is allowed to accept wastes which can be as much as 80% liquid, this component will not consist of brine or similar wastes. Drill cuttings and municipal solid waste do not contain liquids with high concentrations of radioactivity. Any loads, whether they contain liquids or not, that trigger the radiation detectors must be investigated to determine their characteristics and whether they are acceptable for disposal.*

Comment #R13: New York is alone among jurisdictions in failing to recognize deep shale drilling waste as "technologically enhanced naturally occurring radioactive materials" (TENORM), recognizing its potential health and environment impacts, and regulating it accordingly. Instead, under the Department's Parts 380 and 382 regulations, NORM is not regulated unless it is "processed and concentrated," regardless of its potential for harm.

The matter of the Chemung County Landfill expansion proposal is not the forum for urging the Department to change its regulations. However, the Department's Part 360 regulations require the landfill proposal to demonstrate that even "a small contaminant release" of radioactive materials, and specifically Radium-226, because it is a bioaccumulative chemical of concern, would not be threatened "due to proximity to... primary water supply aquifers" or to the Chemung River and the Chesapeake watershed. 6 NYCRR § 360-1.2(a)(150).

Even though the concentrations of Radium in the landfill's leachate are below applicable discharge limits, because the landfill discharges a large volume of leachate, a substantial mass of radionuclides is being released to the Chemung River and stored and managed in close proximity to a principle aquifer. Even "a small contaminant release" of radioactive materials to sensitive environments should be considered "a significant adverse impact on public health, safety, or welfare, the environment or natural resources." 6 NYCRR § 360-1.4(a)(1)(iv). However, given the volume of leachate generated by the landfill, and the larger volume expected under the expansion proposal, it is unreasonable to conclude that the risk of significant adverse impacts posed by the expansion would be insignificant. As USEPA has said, regarding the discharge of BCCs into the sensitive environment of the Great Lakes Basin, because BCCs "accumulate in organisms living in the water and become more concentrated as they move up the food chain–from biota to fish and wildlife to humans," and "[b]ecause the effects of these chemicals are not mitigated by dilution, . . . it is the mass of BCCs that poses a problem, not just the concentration."

Response #R13: *6 NYCRR § 360-1.2(a)(150) states, "(150) Sensitive environment means a site where a solid waste management facility poses a specific threat to the environment or to the public health because a small contaminant release could have a significant impact. This may be due to proximity to other sensitive environments which include, but are not limited to: principal or primary water supply aquifers and public water supply wellhead areas; areas requiring special protection (such as regulated wetlands or the critical habitat of an endangered species); areas containing highly permeable soils or bedrock formations (such as karst carbonate formations or bedrock formations that are serving as major public water supply aquifers and which can readily be contaminated from the surface); or other special circumstances."*

The landfill is not sited over a primary aquifer. For addition information, please refer to the aquifer response section. It is also not in proximity to other sensitive environments such as wetlands, endangered species habitats, or highly permeable soils or bedrock that are serving major public water supplies. The applicant has demonstrated that the potential for release of radioactive materials, specifically Radium-226, are not threatening any "sensitive environments" such as the Chemung River or other environments. Although the Part 380 discharge standards do not apply, Department staff used them as a reference and determined that because the radioactivity levels are well below these discharge standards which were developed with consideration for potential accumulation of radioactivity concentrations in biota there is no significant potential for impact to the environment.

Marvin Resnikoff, PHD – Radiological Comments (RMR1-RMR10)

Comment #RMR1: Marvin Resnikoff, PHD – Radiological Comments

We previously commented on the issue of radioactivity in leachate in May 2010. Our concern was that radium-226 in the landfill would lead to an increased radium concentration in the leachate. This is exactly what has transpired. We note that the measured concentrations from the year 2010 to the year 2013 of radium 226+ 228 in cell IV have steadily increased from 1.44 pCi per liter to 14.18 pCi per liter. Now the County wants to increase the acceptance rate over two times what it previously was, I expect the leachate concentrations to increase accordingly. This means that the lagoon concentrations will also increase and the leachate that passes to the Elmira POTW and the Chemung River will also increase.

Response #RMR1: *Please refer to responses #R2, #R3, and #R4 above.*

Comment #RMR2: Wastewater, in the form of brine and flowback water, is highly radioactive, with concentrations that range up to 26,600 pCi/L. Rock cuttings delivered for disposal at the landfill are accompanied by some volume of these liquid components of the waste stream. Residents have observed truck loads arriving at the landfill gate dripping.

Response #RMR2: *The commenter has made an erroneous assumption that drill cuttings contain significant amounts of brine and flowback. Brine and flowback are unacceptable for disposal in an MSW landfill, including the Chemung County Landfill, because they can contain significant levels of radium. Drill cuttings contain almost no brine. What they contain is residual drilling fluid and only what brine may have been present in the rock in the path of the drill bit. Horizontal fracturing involves "tight formations" in which gas, or brine, move very slowly. Therefore, when drilling, very minimal amounts of brine may be present in the cuttings and drilling muds.*

Only after a well is drilled and drilling muds are removed is a well hydraulically "fractured". The fracturing fluid comes back as flowback and, eventually, the recovered fluids are mostly brine.

The flowback and brine are collected for appropriate treatment, reuse, or disposal. They are not disposed of at the landfill.

Permitted waste haulers are required to prevent dripping and leakage and are subject to the requirements of 6 NYCRR Part 364. We acknowledge that during periods of rain events, there may be instances of incidental dripping but this would not contain any flowback or significant amount of brine as noted above.

Comment #RMR3: In addition, the annual reports submitted to NYSDEC by the landfill indicate "industrial process sludges" from Pennsylvania are disposed in the landfill which could be radioactive oil and gas drilling-related waste. As rock cuttings and other oil and gas drilling-related wastes accumulate in the Chemung landfill, we expect the leachate concentrations will continue to increase, above 14.18 pCi/L Ra-226.

Response #RMR3: *All vehicles delivering waste to the landfill for disposal must pass through the radiation detectors before they proceed to the working face to tip the waste. Any waste load that causes the detectors to alarm must be investigated and a determination must be made as to the proper handling of the waste. Regarding the potential for leachate to increase in Ra-226 levels, see responses to #R3 and #R4 above.*

Comment #RMR4: In the FEIS, DEC found that "Ra-226 is relatively insoluble and has a high affinity to be adsorbed to organic matter. As such, it is unlikely that it would be discharged in the effluent from the wastewater treatment plant." Id., 16. This has not been by found by the PA DEP contractor PESI. PESI found radium-226 concentrations from 40.5 to 26,600 pCi/L in unfiltered samples, and almost the same in filtered samples; 87 .0 to 24, 100 pCi/L. Clearly filtering was not removing the radium, which was in solution, not in particle form. Conventional water treatment plants which remove solids are not be able to effectively remove radium from wastewater unless radium is converted to a solid."

We remain concerned about the potential for bioaccumulation of Radium-226. Radium chemically behaves like calcium and concentrates in bone. The FEIS states," . . . the potential for bioaccumulation are highly speculative, given the low levels of radioactivity present... ". In contrast, if radium is present in water, it can be taken up by fish. Ground up fish (gefilte fish) contains fish bone that can be taken up by humans. In addition, the downstream portion of the Chemung River, below the Elmira water treatment plant that accepts the landfill's leachate, is an important fishing resource.

Response #RMR4: *As stated previously, the levels of radioactivity from drill cuttings are close to or slightly higher than background. The leachate levels are 1 to 2 orders of magnitude lower than Part 380 discharge standards which were developed to be protective of biota including fish to be taken for consumption. For additional information, please refer to response #R10 above. The levels mentioned above are likely from brine sources which are not accepted at the Chemung County landfill.*

Comment #RMR5: Further, if humans intake radium, the radium that is not taken in by human bone, will appear as fecal matter in a POTW, and be released to the Chemung River.

Response #RMR5: *This comment is not related to the Chemung County Landfill expansion.*

Comment #RMR6: "If alpha radiation is present, beta-gamma radiation always would be present and easily detected [by gate portal monitors]." Id., 26. We disagree. Portal monitors are not sufficiently sensitive to detect radium-226 as low as 5 pCi/L. We ran the standard health physics program, Microshield, to calculate whether portal monitors could detect 5 pCi/L Ra-226, and concluded it could not. The FEIS states otherwise: "...the portal radiation monitoring system is sufficiently sensitive to detect waste loads containing such elevated concentration waste materials and prevent their disposal in the landfill." On the other hand, higher concentrations could be detected and have set off alarms at PA landfills. According to the DEP study, "in 2008, TENORM triggered 423 alarms; by 2011, this number had risen to 798 alerts." In one such instance, the MAX Environmental Technologies landfill in South Huntingdon, PA reported direct gamma readings of 96 µR/hr; almost 10 times background levels and 10 times the acceptable level at that particular landfill. In light of the elevated radioactivity in leachate, why there have been no such detections at Chemung County Landfill despite the large volume of rock cuttings disposed (one third to one-half the total waste disposed) raises a concern about the effectiveness of the monitoring system or the alarm setting.

Response #RMR6: *The commenter is referencing a drinking water standard (5 pCi/L) which is not relevant to drill cuttings or NORM coming into a landfill.*

Pennsylvania accepts a wider variety of waste types, including processed and concentrated NORM (commonly known as TENORM) wastes, which New York landfills are not permitted to accept. This is likely why more alarms are triggered in Pennsylvania.

While Naturally Occurring Radioactive Materials (NORM), such as Radium-226, Uranium, and Thorium isotopes, decay via the emission of an alpha particle, Radium-226 also emits a gamma ray at an energy of approximately 186.2 keV. Additionally, in shale drill cuttings, soils and other media, the short-lived decay products of NORM isotopes are also present at equal activities. Many of these decay products emit gamma radiation at a variety of energies that are easily detected by portal detectors.

Comment #RMR7: At the time of the 2010 modification application we raised questions about the use of Co-Physics laboratory. This laboratory was not qualified to examine alpha emitters. I note that the State of New York in investigating rock cuttings to the Allied landfill in Niagara County used TestAmerica lab in Earth City, MO. I feel strongly that samples from the rock cuttings should be sent to the TestAmerica lab in Earth City, MO laboratory for analysis, not only for radium 226 but uranium-238 as well. Co-physics is not qualified to sample alpha emitters.

Response #RMR7: *Alpha emitters are not required to be examined in drill cuttings. Also, laboratories utilized for sample analysis in the State of New York must be ELAP certified. The Co-Physics laboratory is ELAP-certified.*

Comment #RMR8: To quote from a paragraph in our filing in 2010: "Several problems exist concerning contaminated liquid in the landfill. First, municipal waste landfills are lined with a layer of clay and plastic and are not designed to contain low level radioactive wastes. The leachate could mobilize radionuclides and distribute them in other locations throughout the landfill or potentially transport the radium. According to DEP, in 2008, TENORM triggered 423 alarms; by 2011, this number had risen to 798 alerts. In one such instance, the MAX Environmental Technologies landfill in South Huntingdon, PA reported direct gamma readings of 96 μR/hr; almost 10 times background levels and 10 times the acceptable level at that particular landfill. Radionuclides to groundwater sources outside the landfill in the event of a breach in the landfill lining could also occur. Second, the fluid will mix with leachate collected in the Chemung County landfill. This leachate with residues of radionuclides will be sent to the Elmira wastewater treatment plant, which, like the landfill itself, is also not designed to deal with radioactive waste. Radium-226 has a 1600-year half-life, so this is a long-term problem."

Response #RMR8:
Pennsylvania accepts a wider variety of waste types, including TENORM wastes, which are not acceptable at New York landfills.

Drill cuttings and drilling related wastes accepted at the Chemung County Landfill contain Naturally Occurring Radioactive Materials (NORM). They do not contain low-level radioactive waste or naturally occurring materials that have been processed or concentrated (otherwise known as TENORM). To date, no drill cuttings from well development have triggered the radiation detector at the landfill. There are protocols in place to investigate any and all materials that cause an alarm at the landfill. The long-term dose of radium has been modeled and determined to be below levels of concern by the Argonne National Laboratory. For leachate questions, please see Response #R4.

Comment #RMR9: In the FEIS, the County contends, "Ra-226 is relatively insoluble and has a high affinity to be adsorbed to organic matter. As such, it is unlikely that it would be discharged in the effluent from the wastewater treatment plant." FEIS, p.16. This has not been the case in Pennsylvania. Flowback and brine submitted to POTW's show no distinction between filtered and unfiltered leachate. The landfill will accept rock cuttings mixed with flowback water.

Response #RMR9: *The Chemung landfill is not authorized to accept flowback water or brine. Please refer to previous responses regarding the drill cuttings.*

Comment #RMR10: As noted above, because the radionuclide of concern Ra-226 is long lived, increased volumes of drilling-related waste streams will be a long-term problem. This is a problem that will exceed the lifetime of the gas companies and perhaps Chemung County itself. I feel strongly that the State should do a compressive study of the long-term implications of adding this much radium to the Chemung County Landfill. This type of study has not been done.

Response #RMR10: *Because the landfill does not accept drill cuttings above pre-determined activity threshold limits a long term study is not required. However, independent modeling performed by Argonne National Laboratory indicates that the dose at 50 pCi/g (twice the landfill's acceptance limit of 25 pCi/g) still meets allowable dose levels.*

Section II – Public Comments

Air Related Comments

Please see attached Title V Responsiveness Summary for questions and responses.

Radiation-Related Comments (RP1-RP34)

Comment #RP1: While there is an exemption for Naturally Occurring Radioactive Material, wastes from gas drilling are not "naturally occurring". Radioactive leachate from the landfill also raises concerns.

Response #RP1: *See responses #R2, #R3, #R5, #R10, #R13, #RMR1, and #RMR8.*

Comment #RP2: Appendix 13 of the DEC's Revised Draft SGEIS on Hydraulic Fracturing shows that gross alpha and beta in produced brine from vertical Marcellus wells drilled in New York have been as high as 123,000-123,480 pCi/L. Such levels of radioactivity mandate proper handling and tracking of these wastes.

Response #RP2: *Production brine and flowback from gas well development processes are not accepted at the Chemung landfill or any landfill in New York State. See also response #RMR2.*

Comment #RP3: Radioactive materials can cause irreversible damage to human and animal health, and can contaminate water, air, land, soil and food supplies.

Response #RP3: *This is true depending on the isotope(s), activity of said isotope(s), and the volume of material. However, in the case of the drill cuttings accepted by the Chemung Landfill, the level of radioactivity pose no significant risk to workers and members of the public. Allowable activity/concentrations of these naturally occurring radioactive materials (NORM) have been modeled by various entities, including the federal government, and calculated doses are well below acceptable values to members of the public. See responses #R1-R14 and #RMR1-10 for more detailed responses.*

Comment #RP4: DEC's classification of gas drilling waste as Naturally Occurring Radioactive Material (NORM), thereby exempting such wastes from the stringent requirements of New York's low level radioactive waste disposal laws and regulations, is improper.

Response #RP4: *Low-level radioactive waste (LLRW) is a class of waste generated from the nuclear fuel cycle or other licensed uses of radioactive material. The radionuclides in shale are naturally occurring. As such, it is NORM and not LLRW. See also responses #R2.*

Comment #RP5: According to pulmonary physician Earl Robinson who works in Chemung County, the county has the highest death rate from lung cancer in NY State.

Response #RP5: *See the response to comment H1.*

Comment #RP6: Drill cuttings from hydraulic fracturing ("fracking") can contain radium which produces radon gas which is harmful to humans; what testing is done for radon?

Response #RP6: *The average concentration of radium in drill cuttings accepted into the landfill has been within normal background ranges. For a discussion on radon gas, see response to comment #Air 2d.*

Comment #RP7: Drill cuttings from fracking can contain heavy metals such as arsenic, barium, cadmium, lead and mercury which are toxic to humans; what testing is done for heavy metals?

Response #RP7: *Drill cuttings have been characterized by prior analytical testing, including metals, and determined to meet the requirements for municipal solid waste (MSW) landfills.*

Comment #RP8: Trucks entering landfill are tested for gamma radiation, but alpha radiation is more dangerous; why are they only testing for gamma?

Response #RP8: *See response #RMR6 above.*

Comment #RP9: There are known cases of cancer among people living near the landfill; why isn't the NYS Health Department investigating?

Response #RP9: *See the response to comment H1.*

Comment #RP10: Radioactivity in the leachate is increasing; what is the DEC doing about this?

Response #RP10: *See response #R4.*

Comment #RP11: Leachate is processed but radioactivity is not removed; then it goes into the Chemung River and can be taken up by fish.

Response #RP11: *See responses #R4, #R10, and #RMR4.*

Comment #RP12: The landfill is over a major aquifer and should not be accepting radioactive materials and heavy metals.

Response #RP12: *The landfill is not over a primary water supply aquifer or a principal aquifer. See response #R13 and the aquifer comment section.*

Comment #RP13: From personal experience we know that the drill cuttings from the Horizontal Shale Gas Fracking process have concentrated Radium 226 in the fluid present in the cuttings.

Response #RP13: *Cuttings accepted by the landfill contain only minimal amounts of liquid from the rock formation. See also responses #R12 and #RMR2.*

Comment #RP14: It is also common knowledge that Radium 226 is lethal to all human, animal and plant life. There is evidence that alpha emitting radioisotopes such as from Radium 226 is a serious health threat with cancers showing up 30 years after exposure.

Response #RP14: *Please see response #RMR8.*

Comment #RP15: I am a health professional who works on environmental health policy. The proposal to expand the landfill is, as I understand it, based on a DEC provision that classifies fracking waste and drill cuttings as NORM and so this means such waste materials can be disposed of in a county landfill. Given the volume of this waste, the proposal to double the size of the landfill, and the proven hazards to human health of exposure to these toxic materials, this classification under NORM ignores real public health and environmental health harms. The classification is out of date - based on the false concept that naturally occurring is a lesser hazard. That is no longer the case. A number of other NY counties have updated their approach and refused to accept fracking waste. This is wise. I urge the DEC to reconsider this proposal. I understand that Chemung County wants to go ahead, but this position is not based on considering the likely costs to human health, and the risks to county citizens and employees and truckers of possible exposure. To protect human health, this proposal should be denied. Please consult further with the NY Department of Health and at a minimum extend the comment period and conduct further study.

Response #RP15: *The Department has in fact worked closely with the Department of Health Radiation program on this issue. Modeling by Argonne National Laboratory of acceptable limits of radium in drill cuttings has indicated that the dose and risk from allowing cuttings into the landfill is well below allowable values. The landfill does not accept fracking waste such as production brine or flowback from gas well development.*

Comment #RP16: The Marcellus shale deposit is one of the most radioactive deposits in the United States, and the unnatural ("unconventional") process of extraction of this radioactive shale is certainly not appropriately exempted under the language used by the state in its decision that such waste is exempt from regulation under the low-level radioactive waste laws because it's "naturally-occurring radiation." Indeed, thanks to enhanced monitoring at the landfill, the level of radioactivity is increasing, and the leachate is even more radioactive than the shale itself, but as it's in liquid form it is again protected from oversight.

Response #RP16: *See responses #R2, #R3, #R4, and #RP4.*

Comment #RP17: Leachate is taken from the Lowman Landfill in Chemung County is taken to a water treatment plant, and that water from the dump goes into the Chemung River containing heavy metals, and isotopes. My wife has ovarian cancer. My sister had an acute form of Leukemia. The policy of bringing in wastes from drilling in PA and having hundreds of thousands of tons dumped in NY is a scandal.

Response #RP17: *Please see the responses R4 and H1.*

Comment #RP18: Classify gas drill cuttings waste as TENORM, rather than continuing to dishonestly and unlawfully put New Yorkers at terrible health risks by allowing it in our dumps as Naturally Occurring Radioactive Material

Response #RP18: *See also responses #R2, #RMR2, and #RMR8.*

Comment #RP19: NY does not need PA frack waste. Appendix 13 of the DEC's Revised Draft SGEIS on Hydraulic Fracturing shows that gross alpha and beta in produced brine from vertical Marcellus wells drilled in New York have been as high as 123,000 - 123,480 pCi/L. Such levels of radioactivity mandate proper handling and tracking of these wastes.

Response #RP19: *No brine or flowback water from gas well production are allowed in NY state landfills. See responses #R2 and #RMR2.*

Comment #RP20: If the shale-gas drilling waste is "safe," the operators should be able to find a home for it in Pennsylvania, where it is being produced. It is absurd to truck it across the border into New York State.

Response #RP20: *While much, if not most, of the cuttings generated in PA are also disposed of there, the decision to ship cuttings to the landfill in NY from PA may be based on close proximity to the Chemung landfill. The Chemung Landfill is permitted to receive drill cuttings. Please also see response #R2.*

Comment #RP21: I've heard that the radiation detection equipment currently in use has picked up no radioactivity from the trucks entering our dump, implying that the trucks contain no radioactive materials. However, I've also heard that the equipment being used cannot detect alpha radiation, which is the most dangerous. We need to screen for all kinds of lethal or disease-producing materials, not just what's easy to measure.

Response #RP21: *See response #RMR6.*

Comment #RP22a: I urge DEC to deny the permit for the Chemung landfill expansion. Allowing radioactive drilling wastes to be deposited in MSW landfills violates the prohibitions and requirements of NY's low-level radioactive waste laws and regulations.

Response #RP22a: *See response #R2.*

Comment #RP22b: I am grateful that consideration of health risks has led DEC to ban fracking in NY, but many of the same risks are presented when shale drilling wastes from PA are allowed to enter NY municipal landfills.

DEC's treatment of radioactivity risks in the revised draft SGEIS has been criticized by Ivan White, scientist for the National Council on Radiation Protection, as displaying a "cavalier attitude towards human exposure to radioactive material." He stated that the SGEIS's "superficial characterization of radiation risks has prompted warnings from...the EPA whose public comments on the SGEIS reflect deep concerns about DEC's understanding and appreciation of the actual risks posed by radiation." DEC's lack of understanding of these risks is on display in this proceeding.

The Final EIS for the Chemung landfill expansion states that, the gamma detectors at the entrance to the landfill will "mitigate any potential significant adverse environmental impacts to the maximum extent practicable." However, the difficulties of measuring gamma radiation from radium in waste samples are well known. An Earthworks report in April 2015 states, "Gamma radiation is used to measure Ra-226 and Ra-228 in waste samples, but it can take 21 days in the laboratory for [gamma] to emerge... As a result, if waste samples... are not correctly analyzed, radiation concentrations in both waste and landfill leachate-and in turn the potential risks posed to health and the environment-may be underestimated." For this reason, the gamma detectors currently installed at the landfill are not adequate to detect alpha and beta radiation from the radium isotopes in the shale drilling wastes being brought into the Chemung landfill.

Response #RP22b: *See response #RMR6.*

Comment #RP22c: DEC's classification of gas drilling waste as Naturally Occurring Radioactive Material (NORM), thereby exempting such wastes from the stringent requirements of NY's low

level radioactive waste disposal laws and regulations is improper. Drilling wastes are not naturally occurring, but are processed by hydrofracturing and drilling and are processed and concentrated as they are brought to the surface, separated into waste types and gathered into large volumes for deposit in landfills and wastewater treatment plants.

DEC needs to stop categorizing gas drilling wastes as NORM and start subjecting them to the same regulatory requirements that apply to other processed and concentrated radioactive wastes. This means that the radioactivity of the wastes must be carefully monitored by adequate testing procedures. Radioactive gas drilling wastes cannot be disposed of in NY because we have no low-level radioactive waste landfills in NY.

I urge DEC not to issue the permit for the Chemung Landfill expansion. Thank you!

Response #RP22c: *Please the responses #R2 and #RMR2.*

Comment #RP23: Remember, "Ingestion of radium, which is soluble in water, can cause lymphoma, bone cancer, and leukemia,".... "Radium does not simply go away; radium-226 (a derivative of uranium) remains in the environment for 1,600 years."

If the public doesn't want Hydrofracturing in shale here due to the environmental concerns, why would we want the "concerns" part of that equation here? It makes no sense.

Come on already! Enough! This is farmland right next to great lakes. How is this sane in any way? Are we trying to give New York cancer? Do we have a death wish? Is this what we want for our children? This simply boggles the mind!

We must put a stop to putting hazardous and radioactive waste into our landfills–Not expand what we put into them!

The DEC along with FERC are acting rogue agencies not listening to science and disregarding the health of residents. I'm sure they are in the pockets of the gas industry like the rest of these so- called monitoring agencies. This is pathetic.

There is no good reason to take on highly toxic waste from other states which were foolish enough to allow fracking and there are hugely important reasons not to. We should not risk our ground water quality because other states were so foolish!

We don't need the wastes from these environmental disasters stored in NY.

The law is clear and the shale waste is not a naturally occurring piece of waste. Come to the defense of our state land. It is not even supporting NY based workers! It's PA for God's sake.

Response #RP23: *The shale/drill cuttings are in fact naturally occurring. Doses from levels allowed to be disposed of in the landfill are well below limits that would cause any concern or increased risk of cancer. As stated in response to other comments, the waste streams from development of the Marcellus that do contain significant levels of NORM such as flow back, brine, and any treatment wastes from those waste streams, are not accepted at the landfill. The landfill*

does not accept radioactive wastes, toxic wastes, or hazardous wastes. See also responses #R2, #R3, #RMR8, #RMR10, and #H1.

Comment #RP24: DEC's treatment of radioactivity risks in the revised draft SGEIS has been criticized by Ivan White, scientist for the National Council on Radiation Protection, as displaying a "cavalier attitude towards human exposure to radioactive material." He stated that the SGEIS's "superficial characterization of radiation risks has prompted warnings from. The EPA whose public comments on the SGEIS reflect deep concerns about DEC's understanding and appreciation of the actual risks posed by radiation." DEC's lack of understanding of these risks is on display in this proceeding." Why hasn't the DEC done the necessary research to understand these risks?

Response #RP24: *The scope of this responsiveness summary does not include responses to comments on the SGEIS.*

Comment #RP25: The Final EIS for the Chemung landfill expansion states that, the gamma detectors at the entrance to the landfill will "mitigate any potential significant adverse environmental impacts to the maximum extent practicable." However, the difficulties of measuring gamma radiation from radium in waste samples are well known. An Earthworks report in April 2015 states, "Gamma radiation is used to measure Ra-226 and Ra-228 in waste samples, but it can take 21 days in the laboratory for [gamma] to emerge... As a result, if waste samples... are not correctly analyzed, radiation concentrations in both waste and landfill leachate-and in turn the potential risks posed to health and the environment-may be underestimated." For this reason, the gamma detectors currently installed at the landfill are not adequate to detect alpha and beta radiation from the radium isotopes in the shale drilling wastes being brought into the Chemung landfill.

Response #RP25: *The "21 days" referred to by Earthworks is for one of several techniques to accurately analyze laboratory samples for a specific component of NORM. However, it is not relevant to the continuous presence of gamma radiation emitted by radium and its decay products in drill cuttings. See also response #RMR6.*

Comment #RP26: The mandated truck-side detectors are powered on and off at will by the landfill operators at their convenience and judgment. This of course allows them to wave through any truck that might request absolution from radiation monitoring. Although, as noted above, the radiation monitoring is inadequate, what monitoring exits should fulfill at least the following requirements?

1. All monitors to be hardwired with DEC seals in series with the main power line of the facility, so that any interruption would bring all facility operations to a halt.

2. To prevent tampering or jury-rigging of a bypass of the specified serial circuitry, the seal and lockbox containing the radiation monitors should send by radio a constant signal to the local DEC regional office.

3. At the DEC regional office a constant recording of signals from the radiation monitors of all facilities receiving cuttings and fluids from Marcellus shale operations.

4. These would be kept in a manner that distinguishes them according to radiation monitor ID, location at facility, facility ID, and continuous date/time correlation.

5. Such signals should be coded to detect: a) Radiation detected, by strength and radiation source (elemental characteristic) and type (alpha, gamma, beta, etc.); b) Any physical disturbance, motion or contact within the monitors and/or their sealed enclosure; c) EZ-Pass ID and License plate photo of each and every truck or other vehicle passing through the radiation detection area; d) To guard against trucks bypassing the radiation monitored gates altogether, each gate of the facility will be equipped with a constant-duty license plate camera and EZ-pass ID. These data would also be radioed to the regional DEC office, and a continuous record be kept; e) Signal interruption, power on and power off events and other physical events.

6. The records specified above be kept at the regional office, with uninhibited public review during regular office hours.

7. Bi-weekly publication of assessments of all extraordinary events of each facility's radiation and gate traffic monitors. After publication, interested public may request and receive, at DEC expense, copies of the two-week period's recordings of any or all facility's radiation and gate traffic monitors.

8. Monthly purges of the previous month's recordings will be permitted after 15 days grace period for receipt and response to public requests for data, in order to retrieve data storage space.

9. Each regional DEC office will forward copies of the recordings to DEC headquarters, where they will be available for review by subscription to a page on the DEC's website.

Response #RP26: *Detectors present at the facility can readily detect the sources of concern (naturally occurring Uranium and Thorium decay chain isotopes and other gamma emitting radionuclides). They run continuously during landfill operating hours. See also response #RMR6.*

Comment #RP27a: The Marcellus Shale and associated products are radioactive and are being transported from PA to Chemung County landfill. The proposed expansion of the landfill would allow up to 700 tons of waste per day. There is a grave paucity of well-executed research on the radioactivity emitted from fracking waste and the consequent environmental and human health effects, and the Internet is rife with conflicting information. Reports from two consulting firms (one commissioned by the Applicant, one commissioned by the Residents for the Preservation of Lowman and Chemung), and from the USGS, each present different information regarding the

radioactivity of the Marcellus shale and the safety of the transport and waste storage. The reasons for the lack of research and conflicting information are many.

To start, the scientific community is scrambling to keep up with the rapid expansion of fracking activities. Several studies have come out in the past few years on environmental and human health impacts of Marcellus shale fracking and associated processes, like waste transport and storage, but peer reviewed research is a slow process. More studies are in the works and a full evaluation of potential impacts is crucial to make a responsible management decision.

Another challenge of finding good information on the effects of receiving waste from PA surrounds the radioactivity of the waste, the monitoring methods used and the public disclosure of that information. Radioactivity can be difficult to measure. There are two 375P-1000 gamma ray detectors placed at the entrance to the Chemung County landfill. However, a model simulation indicated that these sensors may not detect the anticipated concentrations of radioactivity entering the landfill because they are set to trigger an alarm only when detected radioactivity is above 400 times the background levels (5pCi/g).

Response #RP27a: *This is inaccurate. The "background" value used by the radiation detector is the ambient background value in which the detector is set up. Alarm levels follow strict recommendations by the Conference of Radiation Control Program Directors (CRCPD), a national consortium of radiation programs.*

Comment #RP27b: In addition to issues with methods used to monitor incoming waste, the original reports of radioactivity of incoming waste were not conducted properly. The radioactivity measurement protocol used by CoPhysics, a corporation hired to conduct a study assessing radioactivity in NY landfills that accept fracking waste and Marcellus Shale from PA, is designed for detection of radioactivity in water, not solids, which is primarily what the Chemung County landfill receive1 (although the waste still contains up to 80% residual waste water, which tends to be concentrated with radioactivity due to repeated use and the fact that Radium is soluble in water). In order to properly measure radioactivity in solids, it would first need to be digested in acid.

Response #RP27b: *The methods utilized by CoPhysics are accepted modifications (for solid matrices) to the EPA procedures. See also response #R12.*

Comment #RP27c: The CoPhysics report concluded that the radium levels in landfills across New York were slightly greater than background and less than the EPA cleanup guideline for unrestrictive use (<5 pCi/g), and therefore no further inquiries or mitigation efforts are necessary. There are several oversights in this conclusion. As addressed above, the methods used to measure radium were insufficient. Second, even if their results were correct, it is impossible to predict how much the increased waste intake at the Chemung County landfill will increase radioactivity in the landfill area. Also, the landfill is not isolated but is surrounded by homes. Furthermore, a recent USGS report found that the landfill is close to an aquifer that provides 50 to 170 gallons per minute freshwater to residents across New York. Leachates from the landfill,

which is not equipped to deal with radioactive waste, can make their way into the aquifers and contaminate the drinking water.

Response #RP27c: *As previously discussed, the analytical methods are accepted and allowable for drill cuttings and other solid matrices. Allowable upper limits of accepted activity-concentrations in cuttings have been modeled by a nationally accepted DOE laboratory and deemed to be well below acceptable limits. See also response #RMR8 and responses to M&A comments.*

Comment #RP27d: In addition to using insufficient equipment and protocols to measure radioactivity, the CoPhysics report "proving" low levels of radioactivity in NY landfills and incoming PA shale did not directly measure radium, which is one of the main concerns. They detect a surrogate element, bismuth-214. Measurement of surrogate elements is suitable in cases where the two elements are in secular equilibrium, but that is not the case with radium-226 and bismuth-214 unless they are allowed to equilibrate for 30 days. While the elements should be in equilibrium prior to extraction, removal can upset their equilibrium due to differing solubilities. Therefore, it is likely that the radium measurement was inaccurate.

Response #RP27d: *The laboratory protocols for radium analysis via ingrowth of progeny (Bi-214) are well documented and accepted practice. Once sealed, Radium/Radon progeny in a sample will attain secular equilibrium in approximately 21 days. This is standard practice. Shorter ingrowth times are allowed with pre-determined correction curves. This is allowed as a modification to accepted EPA methodologies.*

Comment #RP27e: While it is true that the issues above are not relevant to the permit application in that they regard more than the amount of waste the facility can receive, they raise an already existing problem with the type of waste the landfill receives, the classification of the waste as naturally occurring radioactive material (NORM) in spite of the fact that it is not in its naturally occurring state or location, and the potential to increase human and environmental health effects. The classification of the Marcellus Shale waste as naturally occurring is inappropriate because it is extracted from the ground and processed on the surface in a way that can concentrate radioactivity. The waste's origin as a natural material does not mean that it is safe, particularly when brought up from 5000 to 9000 feet underground and placed into close proximity with humans. On the contrary, it should be treated as a potentially hazardous material.

Response #RP27e: *The drill cuttings do not exhibit any of the properties of a hazardous material. In the event that a load of drill cuttings trigger a radiation alarm, they will be investigated and handled accordingly. See previous comments and responses for additional details on this topic.*

Comment #RP28: Allowing radioactive drilling wastes to be deposited in MSW landfills violates the prohibitions and requirements of NY's low-level radioactive waste laws and regulations.

I am grateful that consideration of health risks has led DEC to ban fracking in NY, but many of the same risks are presented when shale drilling wastes from PA are allowed to enter NY municipal landfills.

DEC's treatment of radioactivity risks in the revised draft SGEIS has been criticized by Ivan White, scientist for the National Council on Radiation Protection, as displaying a "cavalier attitude towards human exposure to radioactive material." He stated that the SGEIS's "superficial characterization of radiation risks has prompted warnings from...the EPA whose public comments on the SGEIS reflect deep concerns about DEC's understanding and appreciation of the actual risks posed by radiation." DEC's lack of understanding of these risks is on display in this proceeding.

The Final EIS for the Chemung landfill expansion states that, the gamma detectors at the entrance to the landfill will "mitigate any potential significant adverse environmental impacts to the maximum extent practicable." However, the difficulties of measuring gamma radiation from radium in waste samples are well known. An Earthworks report in April 2015 states, "Gamma radiation is used to measure Ra-226 and Ra-228 in waste samples, but it can take 21 days in the laboratory for [gamma] to emerge... As a result, if waste samples... are not correctly analyzed, radiation concentrations in both waste and landfill leachate—and in turn the potential risks posed to health and the environment may be underestimated." For this reason, the gamma detectors currently installed at the landfill are not adequate to detect alpha and beta radiation from the radium isotopes in the shale drilling wastes being brought into the Chemung landfill.

Response #RP28: *See the response to #RMR6 and #RP27d.*

Comment #RP29: DEC's classification of gas drilling waste as Naturally Occurring Radioactive Material (NORM), thereby exempting such wastes from the stringent requirements of NY's low level radioactive waste disposal laws and regulations is improper. Drilling wastes are not naturally occurring, but are processed by hydrofracturing and drilling and are processed and concentrated as they are brought to the surface, separated into waste types and gathered into large volumes for deposit in landfills and wastewater treatment plants.

DEC needs to stop categorizing gas drilling wastes as NORM and start subjecting them to the same regulatory requirements that apply to other processed and concentrated radioactive wastes. This means that the radioactivity of the wastes must be carefully monitored by adequate testing procedures. Radioactive gas drilling wastes cannot be disposed of in NY because we have no low-level radioactive waste landfills in NY.

Response #RP29: *See response #R2.*

Comment #RP30: The failure of the environmental impact analysis in this proceeding to include any meaningful analysis of radiation risks is further evidence of this disregard. The final scoping document states that radioactivity issues "are not environmentally significant based on the

composition of Marcellus shale waste materials that are currently being deposited at the landfill," without examining the radioactivity of the wastes that are being deposited.

Response #RP30: *The landfill has radiation detectors in place used to evaluate whether drilling wastes can be accepted by the landfill. See previous comments and responses.*

Comment #RP31: The Pennsylvania DEP study of radioactivity in gas drilling wastes released in January of this year concludes that "There is little potential for radiation exposure to workers and the public" from the wastes. This conclusion is not supported by the data contained in the report. The data in the report shows significant levels of radioactivity associated with gas field drilling wastes. The PADEP report is deficient in adequately evaluating the health risks presented by the radioactivity brought to the surface in the gas drilling wastes, giving no consideration to radioactivity from the wastes entering soils and water supplies where it can be ingested and lead to years of exposure. The PA study evaluates health exposures as if those exposures were limited to brief periods of time.

Response #RP31: *The subject of this responsiveness summary is the Chemung County Landfill expansion and not the PA DEP report.*

Comment #RP32: There are too many unknown factors, especially regarding radiation. We can develop alternatives for energy and not become a dumping site. Please listen to your constituents, who want clean air, water, and soil, to grow a healthy (economic) future for our families.

Response #RP32: *Radiation factors are known and the required monitoring at the facility will protect human health and the environment. See responses #R4 and #RMR8.*

Comment #RP33: I'd just like to mention I worked in a laboratory with radioactive tracers, and we had to account for every single trace of radioactivity that came in and that was disposed of in that lab. And it just boggles my mind that you're dealing with tons of radioactive material in a very cavalier matter. And so I would just like to implore that this waste should be subject to the low-level radioactive waste laws and not be deposited in Chemung County.

Response #RP33: *See response #R2.*

Comment #RP34: Fracking Material contains radioactive waste: Uranium, Strontium, Radium. Radium produces Radon Gas: Radon 222 decays producing alpha, beta and gamma radiation. The two Radon decay products Polonium 218 and Polonium 214 are the most hazardous. The Alpha radiation produced in the lung can damage the lung's DNA and cause the cell to become mutated which causes lung cancer by hitting and damaging the cancer suppressant gene or by ionization of material surrounding the DNA. The probability of developing lung cancer is related to the concentration of Radon and the Amount of time the person is exposed to Radon.

Approximately 22,000 Radon-induced lung cancer deaths in the United States each year - 11% of the total lung cancer deaths. Radon causes Lung Cancer in both smokers and non-smokers. A Picocurie is 2 nuclear disintegrations/minute. The amount of Radon in ambient air is about 0.4 pCi/L. The average person inhales 8 liters of air a minute, 480 liters an hour, 11,520 liters a day and 4,204,800 liters a year. Because even ambient air contains Radon, this increases the risk of lung cancer in smokers breathing outside air to 3 more people per thousand over a lifetime. Indoor air averages 1.3 pCi/L which equates to 20 more smokers per thousand developing lung cancer. At 2 pCi/L expect 32 smokers per thousand to get lung cancer in a lifetime. The risk increases with the level of Radon exposure. At 20 pCi/L, 260 smokers per thousand would get lung cancer - 25% of the total group. At 20 pCi/L, 36 non-smokers per thousand would get lung cancer. Radon is the number 1 cause of lung cancer in non-smokers. There are areas in Colorado where ambient air in areas that overlie Uranium rock have been measured at 20 pCi/L.

Chemung County has the highest death rate from lung cancer in New York State. Chemung County has high levels of measured Radon. The average indoor Radon Level in the US is 1.13 picocuries/liter of air.

In Chemung County the average Radon level in indoor air is 9.8 picocuries/liter of air which is one of the reasons that Chemung County has such a high cancer rate Radium 226 is present in fracking waste with a higher concentration of Radium found in the Marcellus formation. Radium 226 has a half-life of 1,601 years. Between July of 2013 and December of 2013, 521,852 tons of drilling waste were produced in Pennsylvania and shipped for landfill disposal. New York State received 39,000 tons of that material. There are 4 naturally occurring isotopes of radium, including Radium 228, Radium 226, Radium 224 and Radium 223. Radium 224, 226, and 228 and their decay products are classified as Group 1 carcinogens (known carcinogens to humans).

Two studies of adverse health impacts related to ingested Ra226 date back to Radium Dial painters in the early 1900's. The primary cancer was that of bone with osteosarcoma. The US EPA also notes that in addition to bone cancer, protracted exposure to inhaled or ingested Ra226 can cause lymphoma, leukemia and aplastic anemia. Dust and dirt from mining activity can be inhaled and if the material contains radioactive carcinogens it can be absorbed and deposited in the body where it can damage cells. If Radon is gassing from a Radium source and there is dust, as occurs when running a bulldozer over a multi acre landfill, the Radon tends to attach itself to the dust and is not as easily dispersed. The current acceptable level of risk from residual radioactive materials is 15 mrem/year. In perspective, the average person receives approximately 360 mrem/year from all sources. No mrem/year samples been taken at the landfills receiving Drilling waste from Pennsylvania to my knowledge, nor has there been any testing of Radon gas.

Response #RP34: *To date, no drill cuttings with natural radioactive materials beyond normal values have been disposed of in the landfill. The landfill is not permitted to accept radioactive waste and a strict protocol, including the use of calibrated radiation detectors for each arriving load, is in place to ensure that no radioactive wastes are accepted.*

Modeling performed by Argonne National Laboratory indicates that even at average waste mass concentrations double upper acceptance limits, radiation doses are well below acceptable limits. Radon migration is retarded by landfill design and values of radon at and around the landfill

are and will be expected to remain indistinguishable from natural background. Again, this was modeled by Argonne National Laboratory and results indicated no detectable increase in radon beyond natural background values.

Regarding Health issues, please see "Health Related Comments".

Drilling Waste Comments (D1-D18)

Comment #D1: Please deny all permits to accept radioactive drilling waste from fracked gas wells. Please honor completely our NYS ban on Fracking by rejecting this end-of-the-line component of Frack Infrastructure. New York is not a dump for other state's short sighted involvement with gas and oil extraction industries. To grant permits means the DEC is deliberately ignoring NYS law regarding proper handling, and classification, of radioactive waste. Once radioactive material is extracted from the Earth, it is no longer "naturally-occurring". It is then processed and concentrated and should be subject to proper NYS law. There is no facility in NYS adequately equipped to handle this type of waste. As an under-funded and under-staffed state agency, I do not have faith that the DEC can adequately conserve wild game, healthy forests, and clean water and clean air while simultaneously regulating rogue energy companies that have no interest in conserving NYS natural resources. Will you sacrifice the common good for the "greater" corporate good? I am a father, a teacher, and, along with thousands of others, a fierce Finger Lakes Defender. What we love, we must protect. Do not foul our own nest.

Response #D1: *The Chemung County Landfill is a permitted, double-lined municipal solid waste landfill which is authorized to accept various types of non-hazardous solid wastes including drill cuttings. The new Cell V will be constructed in accordance with the requirements of the Part 360 Solid Waste Regulations.*

The Chemung County Landfill has only applied for an increase in annual waste disposal for waste types which it is currently permitted to receive for disposal. The proposed expansion does not change the waste streams already accepted at the landfill.

See also response #R2.

Comment #D2: Plans for the landfill to accept more drill cuttings from PA fracking operations recklessly exposes NY residents and waterways to radioactive materials and heavy metals. What testing for radioactivity and heavy metals in landfill input and leachate will be in place to protect Chemung residents and water supplies from the fracking detritus generated in PA?

Response #D2: *See responses #D1, #R2, #R4, #R7, #RMR3, #RMR8, #RMR10, and #RP7.*

Comment #D3: I am against the proposed expansion of the Chemung County Landfill and acceptance of fracking waste from Pennsylvania or any other source. I believe this poses an environmental risk that we in New York State do not need. Let Pennsylvania keep their own waste in their own state.

Response #D3: *See responses #R2, #RMR2, #R13, #RMR10, and #RP20.*

Comment #D4: Fracking waste is harmful to children and all of humanity and the environment. Common sense dictates that this should be illegal. This affects all New Yorkers. Ban the disposal of fracking waste!

Response #D4: *See responses #R2, #R3, #R4, #R13, #RMR8, #RMR10, and #RP20.*

Comment #D5: ...the conclusions are clear that both the chemicals used in fracking, as well as potential contaminants picked up from deep in the ground are all dangerous and not worth the risk. That's in addition to the fact that Governor Cuomo, under the guidance of the DEC and the DOH has already banned fracking in New York State because of the many dangers and health risks associated with drilling. Dumping radioactive fracking waste in New York State will expose New Yorkers to the same dangers and health risks this ban was intended to protect us from.

Response #D5: *See responses #R2, #R3, #R4, #R13, #RMR8, #RMR10, and #RP20*

Comment #D6: This action would bring additional amounts of radioactive gas drilling wastes into that public site, a site and a community that is already being subjected to three times more solid drilling waste than any other NYS landfill. The primary responsibility of the people's governing institutions is to protect the health, safety and welfare of the people within their jurisdictions. In light of such facts as: (1) your own data reveals significant levels of radioactivity associated with gas field drilling wastes; (2) the radioactivity of the landfill leachate is on the increase; (3) such waste is shown to be well beyond the radioactive concentrations rightly deemed as NORM; (4) such waste disposal, given its toxic brine levels of alpha and beta radioactivity, demands strict handling and tracking procedures; (5) the evidence and well-recognized truth that radioactive materials cause irreversible damage to human and animal health, to the natural world and to food production; and (6) that the extensive 2600 square-mile Chemung River Watershed flows into the Susquehanna River and the Chesapeake Bay; I find it unacceptable, in violation of both life and your authority, that DEC regulators would approve the doubling in size of the Chemung County Landfill, subjecting the surrounding people, flora and fauna to these cell-altering, life threatening assaults.

Response #D6: *See responses #R2, #R3, #R4, #R13, #RMR8, #RMR10, and #RP20.*

Comment #D7: Doubling the size of the Chemung County landfill so that it can continue to accept radioactive shale gas drilling wastes from out state, when New York State has banned high volume hydraulic fracturing out of concern for its adverse impacts on human health and the environment would be a terribly hypocrisy. The Chemung County landfill already accepts more solid gas drilling waste from Pennsylvania than any other landfill in New York, and it should be accepting none. Unconventional gas drilling is a dangerous, poisonous industry. And without places to dump its waste products, it is an industry that would fail to exist, and should fail to exist. Radioactive materials can cause irreversible damage to health. They can contaminate water, air,

land, soil and food. Leachate from Chemung County landfill already shows increasing levels of radioactivity. The DEC and the County are ignoring this public health threat. At least 15 New York counties already ban the disposal of fracking waste. Chemung County should join them. Governor Cuomo, under the guidance of the DEC and the DOH banned fracking in New York State because of the many dangers and health risks associated with drilling. Dumping radioactive fracking waste in New York State will expose New Yorkers to the same dangers and health risks this ban was intended to protect us from.

Response #D7: *See responses #R2, #R3, #R4, #R13, #RMR8, #RMR10, and #RP20.*

Comment #D8: Drill cuttings from fracking can contain heavy metals such as arsenic, barium, cadmium, lead and mercury which are toxic to humans; what testing is done for heavy metals? There are so many things in our world that we can't readily control or change but this is something that our local government can take a stand on and move in a direction to protect our local environment and thereby protect members of this community.

Response #D8: *See response #RP7.*

Comment #D9: We suggest that Chemung County follow the lead of 15 other counties in New York State that have banned the improper disposal of fracking wastes. The reasons given by the Onondaga County ban make it clear that the toxins and radioactive materials found in fracking waste are "detrimental to the public health". Should not Chemung County lawmakers be just as concerned about Chemung County residents, present and future? Further, we suggest that the Chemung County Landfill be used exclusively as a Chemung County Municipal Solid Waste Facility. This would exclude wastes of any kind from sources other than Chemung County. If this were the case, less rather than more space would be needed to service the needs of the county. The health and well-being of the residents of Chemung County ought to be the primary concern of Chemung County lawmakers. Expansion of the landfill and the continued acceptance of radioactive drill waste from PA does not meet this requirement.

Response #D9: *Drill cuttings may be disposed of in landfills authorized by NYSDEC under permit. The decision whether to accept drill cuttings or other out of county waste is up to the owner and/or operator of the landfill. See responses #R2 and #RP20.*

Comment #D10: Generally, accepting fracking waste in our State after the Governor's decision to ban fracking itself because of its apparently negative consequences for public health, is contrary to findings of both our DEC and Department of Health. To be consistent with these findings, such waste cannot be accepted.

Response #D10: *See responses #D3, #R2, and #RMR2.*

Comment #D11: The Chemung landfill expansion is due in large part to Casella's plan to accept 2-4 times the current level of fracking waste coming in from Pennsylvania gas drilling operations. The Chemung landfill is a top destination in New York for Pennsylvania drilling waste.

Despite widespread concerns, the DEC claims that drilling wastes are exempt from New York's low-level radioactive waste laws, not because they are not radioactive, but because they are "naturally-occurring". Shale gas drilling wastes are processed and concentrated and are being allowed onto roads and into waterways and should be subject to the laws. Radioactive waste expert Dr. Marvin Resnikoff states that Marcellus drill cuttings are unusually radioactive - about 25 times more radioactive than background radioactivity - and they are water soluble.

New York and the DEC, which do not allow fracking due to environmental and health concerns, are allowing the import from PA of radioactive drill cuttings. Casella claims the landfill is not accepting dirt contaminated with chemically-laden fracking waste water, but there are questions in the community about the veracity of this claim. Incoming trucks to the landfill are tested for radioactivity, but are they tested for chemicals?

The Chemung landfill sits near aquifers and water sources. Its liners will leak well before the radioactive waste decays. In addition, Casella's landfill expansion will include the addition of several new leachate lagoons. Leachate is a liquid that drains from the landfill and is stored in lagoons prior to transport to the County Sewer District wastewater treatment facility in Elmira, which is a permitted treatment and disposal plant for leachate. Radioactive dirt coming into the landfill is tested, fills are lined, but leachate is taken directly into our sewer district. Treatment and testing for radioactivity and fracking chemicals is not done at the sewage facility. How is this safe disposal? What good are liners if excessive water is directed into our sewage system? How will the public know what is coming into our landfill and moving out into our water systems?

Response #D11: *As indicated in other responses, Marcellus drill cuttings contain small amounts of naturally-occurring radioactive materials (NORM), they are not considered regulated radioactive waste. Their radioactivity levels are slightly above background and no load has ever approached the 25 times background levels cited in the comment. Furthermore no waste fluids generated during gas well development in the Marcellus are allowed to be applied to roads in NYS.*

Drill cuttings have been characterized by prior analytical testing, including metals, and determined to meet the criteria for disposal in a municipal solid waste (MSW) landfills. All regulated waste is evaluated prior to its acceptance by the landfill. The landfill is designed with a double-composite liner system and leak detection monitoring along with groundwater monitoring. Leachate is and will continue to be monitored via routine sampling, and will be handled in accordance with all regulations. Routine sampling of the leachate allows the department to monitor the composition of the leachate and to react to any changes that might occur over time.
See also responses #R2, #R3, #R4, #R7, #R13, #RMR2, #RMR8, #RMR10, and #RP20.

Comment #D12: Gas-drilling wastes should hardly be considered "natural" and left out in the open with regular garbage to someday become a home development.

Response #D12: *Drill cuttings, like all wastes disposed of at the landfill, are not left in the "open." All waste disposed of at the landfill must be covered at the end of each day. Areas of the landfill that will receive additional waste within 30 days must be covered with daily cover, which is 6 inches of soil or a Department approved substitute. All outside slopes and areas of the landfill that*

will not receive additional waste within 30 day must be covered with intermediate cover, which is 12 inches of clean soil. Each day cover is stripped from a small part of the landfill to establish a working face when waste is deposited that day. The working face must be kept to the minimum size possible during waste placement operation and must be covered with daily or intermediate cover at the end of the working day. The landfill is also subject to a closure plan which will include development and use restrictions. See also response #R2.

Comment #D13: I can't help but think that after what has been revealed thus far in the Skelos trial, there aren't some politicians who are benefitting from this arrangement at the expense of the people who live in the Southern Tier. If accepting drilling waste was safe--even beneficial to the health and well-being of their constituents— if it helped the local economy through increased jobs and tourism, the politicians in Albany and the New York City area would be fighting each other to accept it near their own homes, their constituents' homes and workplaces. But since they're not, you know it's bad news.

Response #D13: *This comment is not related to the permit modification.*

Comment #D14: I am concerned that the CCL is accepting radioactive waste from Fracking sites for many reasons. 1. Why are we still accepting waste from a process that has been banned in NYS for many reasons including health concerns? 2. The DEC's own revised draft SGEIS states that the produced brine from the Marcellus wells has had alpha and beta radiation at levels high enough to mandate proper handling and tracking of the waste. 3. These radioactive materials can cause irreversible health damage to both humans and animals, can contaminate our precious water, soils, and food and air and the long term cumulative exposure has not been evaluated by health experts. 4. The fact that this material is wrongly classified as NORM and therefore exempt from stricter regulations is a crime I think. 5. The landfill relies on testing of radioactivity in the waste that are not efficient enough to accurately test the waste materials. New testing standards are imperative and the thought of increasing capacity when the testing is insufficient is unconscionable. 6. I understand that the levels of radiation detected currently from the landfill are increasing...why compound the issue by accepting more radioactive waste?

Response #D14: *See responses #D3, #R2, #R3, #R4, #R7, #R13, #RMR2, #RMR6, #RMR8, and #RMR10.*

Comment #D15: Radioactive waste can cause irreversible damage to water, air, land, soil and food supplies, and we urge DEC to recognize that gas drilling wastes are not NORM and should be subject to the same regulatory requirements that apply to other processed and concentrated radioactive wastes. For these reasons, we respectfully request that you deny the permits needed to allow Chemung County's expansion plans, and that you make a careful study of the radiation issues presented by shale gas drilling wastes.

Response #D15: *See response #R2.*

Comment #D16: While much of the focus on fracking wastes has rightly focused on the potential of POTWs to release radionuclides into or near drinking water sources, the risk posed by landfill disposal are less well studied. However, so-called "sanitary" landfills are designed to accept common forms of trash, not industrial wastes that are potentially radioactive. The "solid" fracking waste can by regulation be up to 80% liquid, making containment a challenge. The liners uses to create a protective barrier under these landfills are subject to tears and breaches. Moreover, the leachate collected in the landfill drainage systems must be processed, which poses the problematic issue of treating this wastewater at POTWs.... The policy of allowing toxic and hazardous waste to be disposed in sanitary landfills designed to accept municipal and commercial trash or in POTWs designed to provide basic treatment of residential, commercial and pre-treated wastewaters, is a de facto subsidy for the oil and gas industry. By avoiding the appropriate handling and disposal practices—permissible due to regulatory and enforcement gaps—the oil and gas industry is externalizing its costs. Unfortunately in this case New York—a state that has rejected fracking based on a thorough review of the health and environmental risks—ultimately picks up the tab in the form of environmental damage, increased threats to public health and, potentially, down-the-road clean- up costs.

Response #D16: *See responses #R2, #R4, #R7, #R12, #R13, #RMR2, #RMR8, and #RMR10.*

Comment #D17: In the Chemung County Landfill Commissioner Decision, Commissioner Martens states that "The provisions of each Part 360 permit must assure, 'to the extent practicable, that the permitted activity will pose no significant adverse impact on public health, safety or welfare, the environment or natural resources, and that the activity will comply with the [Part 360] requirements' (6 NYCRR 360-1.11[a][1])."

Holdway (2002) provides a comprehensive review of the effects of produced water on marine ecosystems. Similar effects can be anticipated in inland aquatic ecosystems, but to my knowledge, no such review exists. Radium has long been known as a human health hazard and is a potent carcinogen. The combined effects of produced water and radioactivity and their effects on the ecosystem surrounding landfills are not yet understood. Expanding the landfill prior to ensuring there will be "no significant adverse impact on public health, safety or welfare, the environment or natural resources" is negligent.

Response #D17: *Production brine and flowback from the hydraulic fracturing process are not accepted at NYS landfills. See responses #R2, #R4, #R13, #RMR8, and #RMR10.*

Comment #D18: At least 15 New York counties have passed bans on the improper re-use and/or disposal of fracking waste. As the Onondaga County law states, "The toxins and radioactive materials found in hydraulic fracturing waste are detrimental to the public health."

Response #D18: *See responses #R2 and #RP20.*

Comment #T2: I write to express my opposition to... the Expansion of Tonnage at the Chemung County Landfill... First – Our population is dwindling, so our garbage and waste should decrease, not increase. According to the US Census, our county in the year 2000 had just over 91,000 residents. Our projected population for 2020 is about 85,500, a substantial decrease. We're getting smaller; we don't need our tonnage to get bigger. Also, there is nothing attractive about increased tonnage at our dump. Our children will not want to return to live in Chemung County because we have increased tonnage. Nor will people seeking a fresh start in a small, safe, lovely community. However, people have been attracted to our county by our city of beautiful Victorian homes surrounded by green or snow-covered hills. In May of 2014, my husband and I took a tour of Victorian homes, many of them lovingly restored by people new to Chemung County. Now, there's an attraction far weightier than increased tonnage. Let's build our population by providing incentives to refurbish our historic homes and to make our houses and buildings more energy-efficient. This would also, of course, produce jobs. Charleston, South Carolina capitalized on its historic buildings, creating both a preservation industry and a tourist magnet. Should we incentivize such an industry here, and, thus, increase our population, we would still not need to increase tonnage at the dump. Raised awareness of energy efficiency would yield less waste, not more.

Response #T2: *The Department strongly encourages the reduction, reuse, recycling and composting of waste. The County has determined that, there is a need for additional landfill capacity.*

Comment #T3: The proposed increase in capacity would result in an increase in emissions from the use of waste and leachate hauling vehicles as well as landfill equipment. The landfill will generate additional traffic and pollution such as dust and vehicle emissions; both will negatively impact local air quality and human health.

Response #T3: *Please refer to the Title V Responsiveness Summary regarding impacts to dust and vehicle emissions.*

Health-Related Comments (H1-H6)

Comment #H1: As mentioned, there's a cancer cluster in Lowman near the landfill, according to people who live there. I heard that there were nine households affected. Many fracking chemicals cause cancer. I'm concerned that their aquifers, plural, under the proposed expansion that will receive contaminated waste that will go into the Chemung River eventually. Even treated water doesn't lose its radioactivity. The county spends a lot of money touting the recreational opportunities on the Chemung River. Yet scientists say that fish are one thing who accumulate radioactivity and will be unsafe to eat. So I'm asking the DEC, don't grant – to not grant the permit for the Chemung County landfill expansion.

Response #H1: *In response to this comment, the Department contacted the Chemung County Health Department and the NYS Department of Health and received the following response:*

"NYSDOH has reviewed data that is routinely collected and tabulated by the NYSDOH for evidence of cancer "clusters" in the area of the Chemung County landfill. These data come from the New York State Cancer Registry, which, by law, collects information on all cancer cases diagnosed or treated in New York State. In 2013, the NYSDOH completed the Environmental Facilities and Cancer Mapping project (http://www.health.ny.gov/statistics/cancer/environmental_facilities/mapping/) which, among other things, shows highlighted areas where the incidence of 23 different types of cancer is higher or lower than expected. The area in which the landfill is located is in an area where lung cancer is significantly higher than expected. This area includes Elmira and most of central and eastern Chemung County, except for the southern portion of Chemung Town, and parts of neighboring counties. It is one of over 20 such areas found in upstate New York. No other types of cancer were elevated in the area containing the landfill, although both liver and stomach cancers were significantly low there. As reflected in the mapping data, lung cancer rates in Chemung County are higher than the average for New York State. Chemung County is in the second highest fifth of all counties in New York when ranked by lung cancer incidence rate, or the rate of newly diagnosed cases (http://www.health.ny.gov/statistics/cancer/registry/cntymaps/cntymaps.pdf). (Due to the generally poor survival from this disease, lung cancer death rates generally follow the incidence rates.) It should also be pointed out that the proportion of Chemung County adults who currently smoke, 26.4%, is well above the proportion for New York State as a whole (14.4%), and New York State outside of New York City (15.4%).

These readily accessible data do not indicate the presence of any cancer "clusters" in the area of concern. Of course, there could be an unusual occurrence of cancer in a small area such as one particular street that is not reflected in these data. Without information on the specific area or cases of concern, however, it is not possible to assess whether the cancers occurring in that one small area may be unusual, or may be typical of cancers that unfortunately occur in all communities. We therefore invite anyone with specific information to contact the Cancer Surveillance Program of the NYSDOH at canmap@health.state.ny.us or (518) 473-7817 so that we may look into the matter more closely."

Comment #H2: People who live near landfills have been found to have higher rates of certain health problems than the general population. These include low birth weights and cancer. There is strong evidence of a cancer cluster in Lowman near the landfill. Chemung County has the highest death rate from lung cancer in New York State. Existing health problems that may be related to the materials which have been accepted, increase as a landfill's size increases.
At one of the monthly meetings of the Chemung County Legislature last year a thin woman came to the microphone wearing a baseball cap. She commented that those who knew her might not recognize her because she now has cancer, and that she lives very near the landfill. Later in her comments she said that her local mailman wanted to come speak that night too, "but he died of cancer on Friday." It was reported that nine people who live along that road have cancer. I have no documentation to provide, but I urge you to give this letter to the NYS Department of Health and request that they look into the health of folks living in Lowman and the Town of Chemung as well as those who used to live near the landfill but have moved away.

Response #H2: *Please see the answer to question H1 above. The DEIS contains an evaluation of the potential impacts to public health that could result from the Project. Further, NYSDEC and EPA have promulgated landfill development and operation regulations to mitigate public health hazards associated with landfills. By complying with these regulations, the landfill will be*

constructed and operated in such a way that any health risks associated with these health issues will be minimized.

Comment #H3: The Chemung County landfill is now, without hyperbole, a toxic waste dump, an extremely toxic waste dump. It has caused cancer and other ill health maladies to people living nearby. It is destructive to wildlife, water (critical to ALL life), and soil. It is sites like the Chemung County Landfill that will cause the bald eagles to disappear once again from NYS. To permit this landfill to receive more toxins is counter to life, and this must not be allowed to happen.

Response #H3: *The proposed area of landfill expansion does not include any endangered or threatened species, such as the bald eagle, or habitat supporting endangered or threatened species. The landfill expansion will be designed and operated to be protective of the environment. See also response #H1*

Comment #H4: The Chemung County MSW Landfill is located over an aquifer, and additional radioactive materials and metals isn't not protecting the public's drinking water.

Response #H4: *Please see the Aquifer Related comments and the responses to Mr. Abrahams and Mr. Resnikoff's comments that discusses the aquifer issues (#GAA1-#GAA5, and #M&A1-#M&A29)..*

Comment #H5: Health risks will be increased. The danger to public health in our region is far too great to allow this ill-considered proposal to go forward.

Response #H5: *See response #H1.*

Comment #H6: Even if drill cuttings were not the key issue, living close to landfills has been documented as causing serious health hazards. (See the work of David O. Carpenter, PhD, Director for the Institute for Health and the Environment at SUNY Albany and others.) The county's plan to double the size of the Chemung County Landfill and more than double the annual tonnage of waste accepted there shows indifference to county residents living near the landfill. The number of residents in that vicinity who have contracted cancer certainly warrants serious investigation.

Response #H6: *See response #H1.*

Waters and Flooding Comments (W1-W5)

Comment #W1: The Chemung River (which is near the landfill) flows from Painted Post in NY to Sayre, PA where it joins the Susquehanna River that eventually goes to the Chesapeake Bay. In 1972 Hurricane Agnes caused record flooding of the Chemung River. The disasters from Corning to Elmira are well documented. Given more recent additional "hundred-year" flooding in the

EXHIBIT E

NEW YORK STATE DEPARTMENT OF ENVIRONMENTAL CONSERVATION

Division of Materials Management
625 Broadway, Albany, New York 12233-7250
P: (518) 402-8651 | F: (518) 402-9024
www.dec.ny.gov

September 18, 2015

Mr. Jerry Leone
Hakes C&D Debris Landfill
4376 Manning Ridge Road
Painted Post, NY 14870

Dear Mr. Leone:

You are receiving this letter because the landfill you operate has reported disposal of Marcellus Shale drill cuttings within the last three years. Though your facility's operating documents already include criteria for the proper acceptance and disposal of these wastes, the New York State Department of Environmental Conservation wishes to ensure that all facilities operate under consistent requirements. To this end, please review your operating documents and revise them as necessary to ensure that the following criteria below are adhered to:

- Radiation detectors shall be installed, operated, and maintained in accordance with the procedures described in the landfill's operation and maintenance manual for as long as the facility accepts Marcellus Drilling Waste.

- The detector's investigation setpoint is recommended to be set at two times site background radioactivity but under no circumstances should it be set at greater than five times site background radioactivity.

- The radiation detector system should be calibrated at least annually and field checked at least weekly. A log of daily background radiation readings should be maintained at the facility. Documentation related to these activities should be maintained at the facility.

- Landfill staff should be trained annually in detector operating procedures, alarm response procedures, and drilling waste acceptance and handling procedures.

- No regulated radioactive wastes may be accepted.

- No drilling waste may be accepted if the concentration of radium-226 is greater than 25 pCi/g.

- Filter and unfiltered leachate samples from cells that receive drilling waste should be analyzed on a semi-annual basis for the following: radium-226, radium-228, total uranium, and gamma spectrum.

- In order to minimize sediment infiltration, drilling waste should not be placed within six feet of the leachate collection and removal system. In addition, drilling waste should not be placed within ten feet of the exterior of any final cover.

- Immediately notify the Department of any load which triggers the radiation detector.

If you have any questions or need further guidance, please contact your Regional Materials Management Engineer or e-mail us at SWMFprogram@dec.ny.gov.

Sincerely,

Robert J. Phaneuf, P.E.
Acting Director
Division of Materials Management

EXHIBIT F

Exhibit F - Hakes C&D Landfill Leachate Sample Analysis 2012-2017

Parameter	LCS 5/23/2012	Cell 1 Leachate 5/23/2012	Cell 1A Leachate 5/24/2012	Cell 2 Leachate 5/23/2012	Cell 3 Leachate 5/23/2012	Cell 3 Leachate 5/7/2015
Field Parameters						
Field pH (std. units)	7.55	6.94	6.85	6.89	6.84	6.9
ORP (mV)	112.6	-26.1	85.2	135.4	60.4	18.7
Specific Conductivity (us/cm)	2881	4889	7781	4771	7253	2858
Temperature (deg. C)	19.54	19.74	23.61	21.62	21.5	21.2
Turbidity (NTU)	14.8	>1000	9.06	49.1	50.2	27.5
Radionuclide Act + Unc (MDC)[1] µg/L[2]						
Total Uranium (ASTM D5174-97)[3]						
Total Uranium, Dissolved[4] (ASTM D5174-97)						
Radionuclide Act + Unc (MDC) pCi/L[5]						
Radium-226, Dissolved (EPA 903.1)	0.716 ± 0.486 (0.554)	1.05 ± 0.569 (0.571)	0.608 ± 0.406 (0.407)	1.63 ± 0.738 (0.712)	0.731 ± 0.545 (0.737)	0.678 ± 0.778 (0.46)
Radium-226, Total (EPA 903.1)	0.509 ± 0.406 (0.468)	1.05 ± 0.595 (0.630)	1.61 ± 0.665 (0.395)	1.12 ± 0.551 (0.474)	1.23 ± 0.551 (0.145)	3.42 ± 2.15 (0.926)
Radium-228, Dissolved (EPA 904.0)	1.11 ± 0.516 (0.826)	1.12 ± 0.502 (0.816)	0.947 ± 0.542 (0.973)	1.94 ± 0.636 (0.858)	1.27 ± 0.536 (0.820)	0.669 ± 0.466 (0.895)
Radium-228, Total (EPA 904.0)	1.19 ± 0.538 (0.889)	1.32 ± 0.565 (0.901)	1.16 ± 0.565 (0.964)	2.46 ± 0.759 (0.925)	1.20 ± 0.547 (0.906)	2.1 ± 1.01 (1.78)
Total Uranium (EPA 908.0)	-0.960 ± 1.04 (3.10)	-1.15 ± 0.952 (3.01)	0.424 ± 1.27 (2.89)	-1.24 ± 0.917 (3.00)	-1.91 ± 1.35 (3.96)	0.492 ± 0.354 (0.559)
Total Uranium, Dissolved (EPA 908.0)	-0.376 ± 0.713 (1.87)	0.848 ± 1.37 (2.89)	0.281 ± 0.667 (1.48)	-0.299 ± 0.530 (1.48)	0.982 ± 0.792 (1.40)	0.453 ± 0.390 (0.638)
Total Uranium, Dissolved (HASL-300)						
Total Uranium, Total (HASL-300)						
Uranium-234, Dissolved (HASL-300)						
Uranium-234, Total (HASL-300)						
Uranium-235, Dissolved (HASL-300)						
Uranium-235, Total (HASL-300)						
Uranium-238, Dissolved (HASL-300)						
Uranium-238, Total (HASL-300)						
Radionuclide Act + Unc (MDC) pCi/L (EPA 901.1 Results)[6]						
Actinium-228, Dissolved (EPA 901.1)	1.61 ± 8.98 (17.5)	5.15 ± 7.66 (15.0)	-0.056 ± 10.7 (20.8)	-6.610 ± 18.2 (31.1)	12.5 ± 6.37 (12.0)	3.133 ± 16.452 (17.65)
Actinium-228, Total (EPA 901.1)	-1,140 ± 12.4 (18.0)	-6.120 ± 276 (18.4)	-2.640 ± 16.8 (20.0)	-7.120 ± 526 (12.9)	-1.580 ± 15.5 (19.2)	0 ± 7.767 (24.95)
Bismuth-212, Dissolved (EPA 901.1)	-3.330 ± 231 (76.2)	-5,440 ± 2,510 (51.5)	17.0 ± 36.4 (63.4)	-8.130 ± 60.6 (105)	-19,700 ± 175 (65.1)	30.575 ± 41.997 (71.63)
Bismuth-212, Total (EPA 901.1)	16.4 ± 39.0 (68.3)	20.5 ± 41.5 (71.6)	-4,580 ± 183 (43.5)	24.8 ± 28.8 (47.9)	-5,250 ± 1,320 (71.6)	59.801 ± 61.695 (65.04)
Bismuth-214, Dissolved (EPA 901.1)	5.58 ± 4.94 (37.8)	6.57 ± 3.71 (38.3)	0.992 ± 18.5 (34.2)	428 ± 33.1 (54.3)	3.30 ± 3.70 (33.2)	0 ± 6.254 (13.48)
Bismuth-214, Total (EPA 901.1)	-2.330 ± 3.87 (51.8)	6.21 ± 4.50 (38.8)	7.15 ± 19.6 (34.7)	0.471 ± 0.761 (29.4)	1.88 ± 2.10 (51.4)	391.34 ± 48.673 (15.31)
Cesium-134, Dissolved (EPA 901.1)	-1.270 ± 3.32 (5.50)	0.148 ± 4.00 (6.80)	-0.775 ± 2.88 (4.99)	1.57 ± 4.78 (7.36)	-1.970 ± 3.23 (4.98)	0 ± 1.159 (5.007)
Cesium-134, Total (EPA 901.1)	-0.751 ± 3.37 (5.54)	2.14 ± 2.23 (5.83)	-0.641 ± 3.36 (5.85)	1.41 ± 2.44 (3.54)	0.428 ± 0.700 (5.39)	4.086 ± 5.209 (8.05)
Cesium-137, Dissolved (EPA 901.1)	-0.002 ± 2.76 (4.99)	2.49 ± 2.21 (3.50)	0.0580 ± 2.74 (4.95)	1.45 ± 5.36 (8.20)	0.0350 ± 2.24 (4.02)	1.498 ± 3.863 (4.246)
Cesium-137, Total (EPA 901.1)	1.07 ± 2.45 (4.25)	-0.955 ± 2.89 (5.02)	0.289 ± 2.65 (4.75)	1.62 ± 2.06 (3.38)	-0.198 ± 2.70 (4.85)	0 ± 1.553 (7.209)
Lead-212, Dissolved (EPA 901.1)	5.46 ± 7.83 (9.53)	4.04 ± 6.37 (7.92)	0.520 ± 5.33 (9.70)	-1.310 ± 7.89 (13.1)	36.1 ± 21.4 (7.33)	0 ± 4.276 (8.743)
Lead-212, Total (EPA 901.1)	-1.360 ± 8.94 (9.32)	9.01 ± 13.1 (10.5)	8.76 ± 11.2 (9.99)	24.8 ± 14.9 (7.26)	-4.200 ± 181 (12.9)	75.819 ± 27.500 (14.72)
Lead-214, Dissolved (EPA 901.1)	1.35 ± 2.66 (12.5)	12.7 ± 7.35 (8.96)	-2.500 ± 11.3 (12.1)	410 ± 39.2 (15.3)	42.4 ± 24.0 (10.3)	0 ± 5.108 (12.51)
Lead-214, Total (EPA 901.1)	-2.020 ± 11.0 (12.8)	17.4 ± 7.14 (9.61)	7.30 ± 9.32 (12.4)	25.5 ± 20.5 (8.57)	11.1 ± 7.56 (11.1)	± 49.31 (16.39)
Potassium-40, Dissolved (EPA 901.1)	9.24 ± 35.6 (70.9)	125 ± 41.0 (46.0)	129 ± 44.3 (51.3)	35.6 ± 62.3 (116)	179 ± 52.8 (47.0)	65.824 ± 33.329 (41.24)
Potassium-40, Total (EPA 901.1)	-15.600 ± 76.2 (80.1)	138 ± 42.1 (52.0)	17.9 ± 36.2 (69.3)	75.2 ± 35.2 (57.1)	101 ± 45.5 (69.5)	48.42 ± 67.315 (69.57)
Radium-226, Dissolved (EPA 901.1)	39.5 ± 71.9 (121)	-13,000 ± 656 (104)	19.4 ± 63.0 (109)	-65,400 ± 113 (191)	44.5 ± 62.1 (104)	0 ± 60.574 (139.9)
Radium-226, Total (EPA 901.1)	16.7 ± 55.7 (97.4)	24.0 ± 69.5 (119)	52.2 ± 56.1 (79.0)	7.10 ± 58.1 (99.6)	6.37 ± 70.3 (123)	0 ± 89.757 (195.1)
Radium-228, Dissolved (EPA 901.1)	1.61 ± 8.98 (17.5)	5.15 ± 7.66 (15.0)	-0.056 ± 10.7 (20.8)	-6.610 ± 18.2 (31.1)	12.5 ± 6.37 (12.0)	3.133 ± 16.452 (17.65)
Radium-228, Total (EPA 901.1)	-1.140 ± 12.4 (18.0)	-6.120 ± 276 (18.4)	-2.640 ± 16.8 (20.0)	-7.120 ± 526 (12.9)	-1.580 ± 15.5 (19.2)	0 ± 7.767 (24.95)
Thallium-208, Dissolved (EPA 901.1)	-2.450 ± 45.2 (5.70)	1.89 ± 2.04 (4.85)	0.332 ± 0.526 (5.40)	-1.810 ± 5.10 (8.44)	2.89 ± 3.31 (4.31)	1.148 ± 3.810 (4.521)
Thallium-208, Total (EPA 901.1)	-0.961 ± 5.35 (5.53)	-0.886 ± 5.39 (5.67)	-0.167 ± 3.43 (5.93)	1.08 ± 1.06 (4.40)	-1.450 ± 8.41 (5.68)	4.588 ± 4.703 (7.916)
Thorium-227, Dissolved (EPA 901.1)						
Thorium-227, Total (EPA 901.1)						
Thorium-232, Dissolved (EPA 901.1)	1.61 ± 8.98 (17.5)	5.15 ± 7.66 (15.0)	-0.056 ± 10.7 (20.8)	-6.610 ± 18.2 (31.1)	12.5 ± 6.37 (12.0)	0 ± 4602.400 (9295)
Thorium-232, Total (EPA 901.1)	-1.140 ± 12.4 (18.0)	-6.120 ± 276 (18.4)	-2.640 ± 16.8 (20.0)	-7.120 ± 526 (12.9)	-1.580 ± 15.5 (19.2)	3092.4 ± 9641.800 (11800)
Thorium-234, Dissolved (EPA 901.1)	23.6 ± 596 (1,030)	-9.590 ± 404 (691)	-303.000 ± 607 (1,020)	102 ± 122 (211)	-131.000 ± 636 (1,070)	97.813 ± 371.640 (474.1)
Thorium-234, Total (EPA 901.1)	-5.310 ± 562 (973)	-12.600 ± 541 (936)	-345.000 ± 599 (1,170)	-162.000 ± 518 (869)	-219.000 ± 620 (1,050)	0 ± 174.990 (667.4)
Uranium-235 (EPA 901.1)	-9.300 ± 24.7 (41.8)	0.592 ± 0.780 (42.5)	9.42 ± 17.5 (40.6)	-2.120 ± 19.6 (33.4)	-2.530 ± 24.1 (41.8)	0 ± 26.904 (65.25)
Uranium-235, Dissolved (EPA 901.1)	11.4 ± 18.1 (26.1)	30.8 ± 21.7 (27.7)	0.101 ± 19.0 (33.5)	5.34 ± 32.1 (48.9)	0.112 ± 21.4 (36.8)	0 ± 16.781 (40.22)
Uranium-238 (EPA 901.1)	-24.700 ± 105 (127)	66.4 ± 60.9 (83.3)	-11.600 ± 465 (147)	-4.880 ± 195 (116)	58.9 ± 76.0 (129)	0 ± 90.328 (192.5)
Uranium-238, Dissolved (EPA 901.1)	34.1 ± 67.1 (114)	29.6 ± 66.2 (112)	22.6 ± 74.5 (130)	34.7 ± 825 (1,430)	-1.830 ± 105 (119)	0 ± 52.151 (131.1)

Notes:

1.) Act + Unc (MDC) = Activity ± Uncertainty (Minimum Detectable Concentration)

2.) µg/L = micrograms per liter

3.) Each of EPA 901.1, EPA 903.1, EPA 904.0, EPA 908.0, ASTM D5174-97, and HASL-300 are laboratory analysis methods.

4.) Dissolved - Indicates sample filtered with 0.45 micron filter prior to analysis.

5.) pCi/L = picocuries per liter

6.) The EPA 901.1 method results are for non-quantitative purposes only due to the method's high degree of uncertainty.

Exhibit F - Hakes C&D Landfill Leachate Sample Analysis 2012-2017

Parameter	Cell 3 Leachate 11/11/2015	Cell 3 Leachate 5/4/2016	Cell 3 Leachate 11/18/2016	Cell 3 Leachate 5/8/2017	Cell 3 Leachate 11/17/2017	Cell 4 Leachate 5/23/2012
Field Parameters						
Field pH (std. units)	6.8	6.79	6.88	6.78	6.91	6.42
ORP (mV)	98.1	41.7	32.4	-323.8	-151.7	7.9
Specific Conductivity (us/cm)	3387	4086	6539	9085	7443	1956
Temperature (deg. C)	16.02	18	21.61	21.7	16.8	19.36
Turbidity (NTU)	89.4	606	100	69.2	140	20.1
Radionuclide Act + Unc (MDC)[1] µg/L[2]						
Total Uranium (ASTM D5174-97)[3]			0.000995 ± 0.049 (0.385)	0.00251 ± 0.127 (0.385)		
Total Uranium, Dissolved[4] (ASTM D5174-97)			0.00109 ± 0.047 (0.385)	0.00359 ± 0.156 (0.385)		
Radionuclide Act + Unc (MDC) pCi/L[5]						
Radium-226, Dissolved (EPA 903.1)	1.29 ± 0.935 (1.14)	0.442 ± 0.580 (0.966)	0.937 ± 0.952 (1.44)	1.75 ± 1.10 (0.473)	2.69 ± 0.78 (0.22)	0.348 ± 0.365 (0.539)
Radium-226, Total (EPA 903.1)	1.43 ± 1.03 (1.26)	1.66 ± 0.976 (0.966)	1.12 ± 0.616 (0.549)	2.85 ± 1.53 (0.552)	2.8 ± 0.78 (0.17)	0.574 ± 0.404 (0.422)
Radium-228, Dissolved (EPA 904.0)	1.33 ± 0.526 (0.815)	0.985 ± 0.458 (0.78)	1.15 ± 0.499 (0.632)	3.25 ± 0.960 (1.15)	1.83 ± 0.57 (0.62)	0.694 ± 0.475 (0.896)
Radium-228, Total (EPA 904.0)	1.38 ± 0.591 (0.948)	1.4 ± 0.555 (0.862)	1.35 ± 0.519 (0.795)	3.9 ± 1.30 (1.68)	2.02 ± 0.63 (0.71)	1.10 ± 0.563 (0.976)
Total Uranium (EPA 908.0)	2.09 ± 0.708 (0.709)	1.41 ± 0.607 (0.886)				0.772 ± 0.745 (1.40)
Total Uranium, Dissolved (EPA 908.0)	1.36 ± 0.658 (0.922)	1.76 ± 0.549 (0.543)				0.350 ± 0.641 (1.38)
Total Uranium, Dissolved (HASL-300)					0.29 ± 0.19 (0.22)	
Total Uranium, Total (HASL-300)					0.31 ± 0.15 (0.15)	
Uranium-234, Dissolved (HASL-300)					0.19 ± 0.13 (0.15)	
Uranium-234, Total (HASL-300)					0.16 ± 0.11 (0.13)	
Uranium-235, Dissolved (HASL-300)					-0.015 ± 0.078 (0.142)	
Uranium-235, Total (HASL-300)					0.045 ± 0.063 (0.094)	
Uranium-238, Dissolved (HASL-300)					0.11 ± 0.11 (0.16)	
Uranium-238, Total (HASL-300)					0.105 ± 0.085 (0.096)	
Radionuclide Act + Unc (MDC) pCi/L (EPA 901.1 Results)[6]						
Actinium-228, Dissolved (EPA 901.1)	9.101 ± 26.524 (34.5)	3.116 ± 16.467 (17.66)	0.255 ± 40.602 (42.85)	0 ± 10.788 (18.93)	33 ± 18 (27)	-0.042 ± 0.0720 (16.1)
Actinium-228, Total (EPA 901.1)	0 ± 4.384 (21.4)	0 ± 5.485 (19.92)	8.262 ± 25.890 (31.97)	37.525 ± 65.041 (71.44)	3 ± 21 (36)	4.03 ± 4.90 (17.3)
Bismuth-212, Dissolved (EPA 901.1)	0 ± 36.567 (113)	10.028 ± 64.348 (71.71)	83.393 ± 130.280 (137.1)	0 ± 31.352 (64.85)	69 ± 58 (92)	1.83 ± 35.4 (64.3)
Bismuth-212, Total (EPA 901.1)	5.033 ± 66.631 (74.22)	49.256 ± 47.540 (48.41)	13.73 ± 105.030 (122.1)	35.408 ± 196.270 (221)	85 ± 58 (90)	0.646 ± 31.7 (57.4)
Bismuth-214, Dissolved (EPA 901.1)	14.895 ± 13.603 (16.48)	11.604 ± 7.496 (11.14)	1320.9 ± 148.240 (23.77)	64.221 ± 13.485 (10.56)	3 ± 16 (27)	8.50 ± 5.78 (31.3)
Bismuth-214, Total (EPA 901.1)	28.356 ± 9.066 (8.704)	16.287 ± 8.662 (8.697)	63.664 ± 19.257 (17.07)	2162.4 ± 243.650 (42.65)	14.6 ± 8.4 (12.9)	43.1 ± 9.54 (36.2)
Cesium-134, Dissolved (EPA 901.1)	5.375 ± 5.540 (6.026)	1.144 ± 2.503 (4.271)	0 ± 3.177 (14.32)	2.105 ± 3.133 (4.385)	3.3 ± 5.8 (9.1)	-0.555 ± 3.52 (4.61)
Cesium-134, Total (EPA 901.1)	3.052 ± 3.069 (5.64)	0.916 ± 1.468 (5.868)	1.439 ± 8.189 (9.31)	0 ± 5.685 (21.84)	-3 ± 4 (7)	-2.850 ± 3.70 (6.00)
Cesium-137, Dissolved (EPA 901.1)	0 ± 0.815 (8.748)	0 ± 0.609 (5.05)	-8.064 ± 12.680 (13.25)	-2.202 ± 4.723 (4.966)	-3.5 ± 4 (7)	0.224 ± 2.50 (4.43)
Cesium-137, Total (EPA 901.1)	-0.736 ± 4.737 (5.219)	0.558 ± 4.040 (4.51)	0 ± 0.815 (11.2)	1.637 ± 16.714 (16.72)	-4.5 ± 4.3 (7.8)	1.91 ± 1.72 (2.65)
Lead-212, Dissolved (EPA 901.1)	0 ± 8.755 (17.06)	12.262 ± 16.952 (9.224)	333.18 ± 72.729 (27.39)	4.075 ± 5.714 (7.888)	-0.7 ± 8.6 (14.4)	0.147 ± 5.23 (9.35)
Lead-212, Total (EPA 901.1)	1.962 ± 6.949 (8.667)	14.027 ± 16.916 (9.201)	0 ± 9.517 (20.59)	405.46 ± 77.374 (40.77)	2 ± 10 (17)	11.0 ± 13.2 (10.5)
Lead-214, Dissolved (EPA 901.1)	7.03 ± 18.878 (24.52)	24.509 ± 17.640 (10.63)	1403.9 ± 158.710 (32.38)	48.159 ± 13.024 (11.74)	9.6 ± 7.7 (12.3)	10.4 ± 6.01 (7.86)
Lead-214, Total (EPA 901.1)	14.132 ± 8.782 (11.13)	24.291 ± 8.950 (9.812)	77.705 ± 19.834 (17)	1690.3 ± 193.770 (80.08)	-7 ± 13 (23)	38.0 ± 10.6 (9.95)
Potassium-40, Dissolved (EPA 901.1)	0 ± 53.073 (153.1)	122.56 ± 42.315 (43.07)	104.53 ± 111.900 (115.2)	163.99 ± 66.366 (54.83)	140 ± 100 (160)	1.45 ± 29.8 (57.8)
Potassium-40, Total (EPA 901.1)	108.09 ± 38.360 (39.08)	59.436 ± 60.524 (64.51)	0 ± 74.192 (170.3)	129.63 ± 218.020 (226.4)	90 ± 110 (190)	-22.200 ± 77.2 (63.8)
Radium-226, Dissolved (EPA 901.1)	0 ± 102.540 (200.3)	0 ± 62.447 (143.8)	0 ± 245.640 (379.7)	19.146 ± 84.796 (108.7)	39 ± 90 (150)	-11.700 ± 642 (93.9)
Radium-226, Total (EPA 901.1)	0 ± 68.875 (131.1)	31.779 ± 97.378 (122.7)	133.98 ± 155.690 (187.1)	132.62 ± 384.790 (469.5)	61 ± 67 (110)	-1.850 ± 98.6 (116)
Radium-228, Dissolved (EPA 901.1)	9.101 ± 26.524 (34.5)	3.116 ± 16.467 (17.66)	0.255 ± 40.602 (42.85)	0 ± 10.788 (18.93)	33 ± 18 (27)	-0.042 ± 0.0720 (16.1)
Radium-228, Total (EPA 901.1)	0 ± 4.384 (21.4)	0 ± 5.485 (19.92)	8.262 ± 25.890 (31.97)	37.525 ± 65.041 (71.44)	3 ± 21 (36)	4.03 ± 4.90 (17.3)
Thallium-208, Dissolved (EPA 901.1)	0 ± 4.078 (10.77)	3.126 ± 5.628 (5.521)	0 ± 12.981 (13.52)	2.794 ± 4.492 (4.558)	0.7 ± 5.9 (9.9)	1.39 ± 2.46 (4.28)
Thallium-208, Total (EPA 901.1)	0 ± 2.884 (5.473)	3.538 ± 4.124 (4.767)	0 ± 2.438 (11.34)	0 ± 10.451 (24.02)	-3.3 ± 6.3 (10.8)	-0.364 ± 3.23 (4.94)
Thorium-227, Dissolved (EPA 901.1)					10 ± 30 (50)	
Thorium-227, Total (EPA 901.1)					3 ± 27 (45)	
Thorium-232, Dissolved (EPA 901.1)	2903.2 ± 3952.500 (4780)	1475.1 ± 7430.700 (9194)	4032.6 ± 19159.000 (23230)	3383 ± 7122.000 (8586)	33 ± 18 (27)	-0.042 ± 0.0720 (16.1)
Thorium-232, Total (EPA 901.1)	0 ± 3404.400 (9737)	1617.5 ± 7939.800 (9788)	4200.7 ± 4129.300 (4907)	3973.6 ± 10832.000 (13060)	3 ± 21 (36)	4.03 ± 4.90 (17.3)
Thorium-234, Dissolved (EPA 901.1)	37.85 ± 230.230 (293.8)	93.454 ± 384.710 (488.8)	78.446 ± 1038.900 (1298)	62.96 ± 78.827 (488.5)	-34 ± 83 (140)	-175.000 ± 551 (928)
Thorium-234, Total (EPA 901.1)	0 ± 187.440 (536.1)	152.1 ± 424.640 (536)	20.553 ± 256.350 (325.1)	119.93 ± 619.240 (752.3)	12 ± 95 (159)	260 ± 583 (973)
Uranium-235 (EPA 901.1)						-1.220 ± 22.6 (36.7)
Uranium-235, Dissolved (EPA 901.1)						-12.900 ± 21.9 (36.5)
Uranium-238 (EPA 901.1)						-3.260 ± 409 (126)
Uranium-238, Dissolved (EPA 901.1)						15.3 ± 64.6 (112)

Notes:

1.) Act + Unc (MDC) = Activity ± Uncertainty (Minimum Detectable Concentration)

2.) µg/L = micrograms per liter

3.) Each of EPA 901.1, EPA 903.1, EPA 904.0, EPA 908.0, ASTM D5174-97, and HASL-300 are laboratory analysis methods.

4.) Dissolved - Indicates sample filtered with 0.45 micron filter prior to analysis.

5.) pCi/L = picocuries per liter

6.) The EPA 901.1 method results are for non-quantitative purposes only due to the method's high degree of uncertainty.

Exhibit F - Hakes C&D Landfill Leachate Sample Analysis 2012-2017

Parameter	Cell 4 Leachate 5/7/2015	Cell 4 Leachate 11/11/2015	Cell 4 Leachate 5/4/2016	Cell 4 Leachate 11/16/2016	Cell 4 Leachate 6/6/2017	Cell 4 Leachate 11/17/2017
Field Parameters						
Field pH (std. units)	6.92	7.09	6.97	7.14	6.83	7.14
ORP (mV)	142.5	-143.1	29	35.8	2.8	-213.7
Specific Conductivity (us/cm)	5402	8252	7288	6235	6304	6889
Temperature (deg. C)	22.5	17.09	17.9	21.58	19.7	16.6
Turbidity (NTU)	15.4	52.1	35.9	26.1	14.7	42.1
Radionuclide Act + Unc (MDC)[1] µg/L[2]						
Total Uranium (ASTM D5174-97)[3]				0.000329 ± 0.016 (0.385)	0.000764 ± 0.029 (0.385)	
Total Uranium, Dissolved[4] (ASTM D5174-97)				0.000364 ± 0.014 (0.385)	0.000711 ± 0.033 (0.385)	
Radionuclide Act + Unc (MDC) pCi/L[5]						
Radium-226, Dissolved (EPA 903.1)	1.57 ± 1.04 (0.472)	4.59 ± 1.97 (1.64)	0.756 ± 0.493 (0.506)	0.483 ± 0.490 (0.742)	2.57 ± 1.30 (0.436)	1.59 ± 0.51 (0.24)
Radium-226, Total (EPA 903.1)	5.19 ± 2.54 (0.827)	5.11 ± 1.38 (0.213)	3.28 ± 1.20 (0.278)	2.43 ± 0.927 (0.577)	2.58 ± 1.51 (1.79)	2.53 ± 0.72 (0.21)
Radium-228, Dissolved (EPA 904.0)	1.64 ± 0.630 (0.97)	5.92 ± 1.35 (0.996)	3.38 ± 0.867 (0.891)	2.68 ± 0.751 (0.819)	3.86 ± 0.957 (0.821)	2.48 ± 0.71 (0.63)
Radium-228, Total (EPA 904.0)	3.77 ± 1.17 (1.6)	5.13 ± 1.27 (1.07)	3.14 ± 0.847 (0.878)	2.2 ± 0.750 (1.07)	2.72 ± 0.892 (1.26)	2.22 ± 0.68 (0.74)
Total Uranium (EPA 908.0)	0.272 ± 0.337 (0.573)	1.29 ± 0.587 (0.753)	0.402 ± 0.314 (0.518)			
Total Uranium, Dissolved (EPA 908.0)	0.551 ± 0.360 (0.559)	1.15 ± 0.544 (0.704)	0.806 ± 0.368 (0.484)			
Total Uranium, Dissolved (HASL-300)						0.48 ± 0.18 (0.1)
Total Uranium, Total (HASL-300)						0.56 ± 0.19 (0.1)
Uranium-234, Dissolved (HASL-300)						0.26 ± 0.12 (0.07)
Uranium-234, Total (HASL-300)						0.29 ± 0.13 (0.07)
Uranium-235, Dissolved (HASL-300)						0.01 ± 0.055 (0.082)
Uranium-235, Total (HASL-300)						0.026 ± 0.055 (0.086)
Uranium-238, Dissolved (HASL-300)						0.21 ± 0.11 (0.07)
Uranium-238, Total (HASL-300)						0.25 ± 0.12 (0.07)
Radionuclide Act + Unc (MDC) pCi/L (EPA 901.1 Results)[6]						
Actinium-228, Dissolved (EPA 901.1)	0 ± 4.640 (39.33)	0 ± 17.365 (38.32)	0 ± 11.596 (22.52)	0 ± 15.614 (44.33)	0 ± 26.996 (53.58)	9 ± 16 (26)
Actinium-228, Total (EPA 901.1)	5.215 ± 30.714 (39.31)	12.968 ± 14.548 (16.16)	2.636 ± 26.970 (38.33)	35.329 ± 39.446 (43.02)	8.678 ± 11.881 (18.84)	26 ± 15 (24)
Bismuth-212, Dissolved (EPA 901.1)	30.809 ± 75.290 (90.19)	20.005 ± 127.980 (149.1)	0 ± 13.451 (88.26)	118.28 ± 173.930 (134.3)	0 ± 72.210 (189.8)	1 ± 52 (89)
Bismuth-212, Total (EPA 901.1)	9.62 ± 100.500 (121)	0 ± 10.427 (74.22)	0 ± 46.219 (152.9)	0 ± 56.604 (191.1)	31.323 ± 45.410 (47.8)	56 ± 48 (76)
Bismuth-214, Dissolved (EPA 901.1)	2.129 ± 18.181 (23.4)	25.958 ± 18.004 (21.03)	4.12 ± 10.106 (11.53)	1013.4 ± 116.970 (27.6)	2475.4 ± 266.380 (30.1)	1 ± 11 (22)
Bismuth-214, Total (EPA 901.1)	0 ± 7.147 (26.3)	37.991 ± 10.867 (10.07)	0 ± 12.030 (25.37)	1108.6 ± 132.190 (29.22)	22.837 ± 9.837 (9.001)	18.4 ± 8.7 (13.1)
Cesium-134, Dissolved (EPA 901.1)	-0.853 ± 8.882 (10.27)	2.813 ± 7.274 (8.353)	0.885 ± 4.648 (5.224)	2.466 ± 4.890 (15)	0 ± 5.572 (13.46)	-3 ± 3.7 (6.6)
Cesium-134, Total (EPA 901.1)	0 ± 1.671 (11.7)	3.398 ± 2.537 (5.771)	4.324 ± 6.376 (7.154)	0 ± 2.897 (15.61)	0.5 ± 4.213 (4.603)	-0.8 ± 3.9 (6.6)
Cesium-137, Dissolved (EPA 901.1)	0 ± 2.578 (12.87)	2.643 ± 5.782 (6.649)	0.355 ± 4.492 (5.05)	-4.314 ± 11.841 (12.52)	0 ± 2.460 (12.96)	-0.1 ± 3.8 (6.5)
Cesium-137, Total (EPA 901.1)	0 ± 1.997 (11.62)	-1.168 ± 4.551 (4.995)	-3.805 ± 11.382 (12.87)	0 ± 3.051 (15.6)	-0.025 ± 3.741 (4.245)	-0.2 ± 3.7 (6.3)
Lead-212, Dissolved (EPA 901.1)	4.472 ± 13.018 (16.63)	4.828 ± 12.260 (15.62)	12.925 ± 12.705 (9.224)	276.33 ± 79.596 (26.23)	295.32 ± 41.236 (28.58)	0.4 ± 8.2 (13.8)
Lead-212, Total (EPA 901.1)	0 ± 7.818 (17.3)	2.952 ± 5.243 (8.61)	1.214 ± 14.507 (18.13)	298.11 ± 55.113 (32.62)	1.701 ± 8.079 (9.9)	8.5 ± 6.4 (10.1)
Lead-214, Dissolved (EPA 901.1)	0 ± 11.097 (22.99)	30.886 ± 16.585 (19.84)	18.684 ± 14.090 (11.07)	1124.9 ± 128.370 (26.33)	2549.1 ± 273.010 (30.66)	-9 ± 12 (20)
Lead-214, Total (EPA 901.1)	2.145 ± 14.761 (19.96)	48.796 ± 12.998 (9.549)	0 ± 11.346 (22.78)	1197.5 ± 141.560 (38.89)	8.983 ± 9.319 (11.85)	14.4 ± 7.4 (11.3)
Potassium-40, Dissolved (EPA 901.1)	140.64 ± 84.435 (110.9)	83.108 ± 132.290 (153.1)	260.5 ± 66.627 (50.55)	160.56 ± 97.218 (102.9)	210.6 ± 135.230 (134.5)	135 ± 92 (146)
Potassium-40, Total (EPA 901.1)	93.499 ± 118.740 (143.1)	151.28 ± 51.200 (48.24)	197.9 ± 94.924 (114)	143.06 ± 166.720 (181.5)	129.88 ± 46.728 (45.37)	145 ± 90 (142)
Radium-226, Dissolved (EPA 901.1)	0 ± 102.250 (205.6)	64.564 ± 155.530 (200.3)	36.587 ± 98.448 (122.2)	0 ± 163.030 (334.4)	0 ± 191.920 (368.4)	3 ± 95 (158)
Radium-226, Total (EPA 901.1)	0 ± 89.553 (193.9)	91.528 ± 107.210 (128.3)	0 ± 54.840 (249.5)	196.74 ± 307.810 (370.4)	0 ± 69.468 (136.5)	40 ± 170 (280)
Radium-228, Dissolved (EPA 901.1)	0 ± 4.640 (39.33)	0 ± 17.365 (38.32)	0 ± 11.596 (22.52)	0 ± 15.614 (44.33)	0 ± 26.996 (53.58)	9 ± 16 (26)
Radium-228, Total (EPA 901.1)	5.215 ± 30.714 (39.31)	12.968 ± 14.548 (16.16)	2.636 ± 26.970 (38.33)	35.329 ± 39.446 (43.02)	8.678 ± 11.881 (18.84)	26 ± 15 (24)
Thallium-208, Dissolved (EPA 901.1)	2.444 ± 7.676 (9.584)	0.577 ± 7.654 (10.11)	2.226 ± 3.095 (6.335)	5.178 ± 8.516 (12.66)	0 ± 6.890 (15.52)	5.9 ± 4 (6.2)
Thallium-208, Total (EPA 901.1)	2.827 ± 7.710 (9.576)	0 ± 2.163 (4.908)	0 ± 3.268 (14.3)	0 ± 2.668 (21.1)	3.167 ± 4.550 (5.039)	1.8 ± 6.1 (10.1)
Thorium-227, Dissolved (EPA 901.1)						6 ± 28 (47)
Thorium-227, Total (EPA 901.1)						-28 ± 21 (37)
Thorium-232, Dissolved (EPA 901.1)	4249.3 ± 3856.600 (4303)	3454.6 ± 4185.800 (5031)	1659.5 ± 7064.900 (8744)	2827.7 ± 18288.000 (22220)	-2380.5 ± 8049.000 (9653)	9 ± 18 (26)
Thorium-232, Total (EPA 901.1)	1865.2 ± 3876.700 (4514)	0 ± 3284.900 (9901)	2622.1 ± 4837.600 (5873)	-1184 ± 9164.700 (11140)	-1264.3 ± 7708.100 (9538)	26 ± 15 (24)
Thorium-234, Dissolved (EPA 901.1)	0 ± 134.510 (329.1)	69.849 ± 245.530 (310)	0 ± 221.480 (509.1)	0 ± 276.650 (1242)	89.479 ± 439.130 (527.9)	26 ± 82 (137)
Thorium-234, Total (EPA 901.1)	0 ± 120.180 (301.3)	0 ± 127.450 (517)	0 ± 112.980 (366.1)	98.264 ± 499.240 (609.5)	161.6 ± 369.400 (464)	10 ± 160 (270)
Uranium-235 (EPA 901.1)	0 ± 20.011 (60.11)					
Uranium-235, Dissolved (EPA 901.1)	8.353 ± 44.770 (55.55)					
Uranium-238 (EPA 901.1)	81.058 ± 113.800 (146.5)					
Uranium-238, Dissolved (EPA 901.1)	0 ± 75.322 (172.7)					

Notes:

1.) Act + Unc (MDC) = Activity ± Uncertainty (Minimum Detectable Concentration)

2.) µg/L = micrograms per liter

3.) Each of EPA 901.1, EPA 903.1, EPA 904.0, EPA 908.0, ASTM D5174-97, and HASL-300 are laboratory analysis methods.

4.) Dissolved - Indicates sample filtered with 0.45 micron filter prior to analysis.

5.) pCi/L = picocuries per liter

6.) The EPA 901.1 method results are for non-quantitative purposes only due to the method's high degree of uncertainty.

Exhibit F - Hakes C&D Landfill Leachate Sample Analysis 2012-2017

Parameter	Cell 5 Leachate 5/23/2012	Cell 5 Leachate 11/14/2012	Cell 5 Leachate 12/4/2012	Cell 5 Leachate 5/15/2013	Cell 5 Leachate 11/6/2013	Cell 5 Leachate 5/15/2014
Field Parameters						
Field pH (std. units)	6.48	6.92	6.97	6.78	6.88	6.59
ORP (mV)	20.1	6.7	13.8	-98.7	-6.5	-5.4
Specific Conductivity (us/cm)	3316	6506	5090	5677	5594	5636
Temperature (deg. C)	20.9	13.74	22.59	19.88	16.46	18.77
Turbidity (NTU)	17.8	777	565	469	69.1	40.2
Radionuclide Act + Unc (MDC)[1] µg/L[2]						
Total Uranium (ASTM D5174-97)[3]						
Total Uranium, Dissolved[4] (ASTM D5174-97)						
Radionuclide Act + Unc (MDC) pCi/L[5]						
Radium-226, Dissolved (EPA 903.1)	0.427 ± 0.326 (0.165)	0.877 ± 0.746		1.03 ± 0.797	0.771 ± 0.945 (1.32)	2.44 ± 1.06 (0.964)
Radium-226, Total (EPA 903.1)	0.888 ± 0.494 (0.172)	0.733 ± 1.76		2.12 ± 1.35	2.57 ± 1.71 (0.774)	1.40 ± 1.41 (1.87)
Radium-228, Dissolved (EPA 904.0)	1.26 ± 0.580 (0.965)	0.939 ± 0.545		1.56 ± 0.608	1.92 ± 0.795 (1.21)	1.15 ± 0.500 (0.815)
Radium-228, Total (EPA 904.0)	0.549 ± 0.451 (0.894)	1.09 ± 0.638		2.37 ± 1.35	2.29 ± 2.48 (4.47)	0.746 ± 0.525 (0.998)
Total Uranium (EPA 908.0)	-0.524 ± 0.415 (1.38)		0.133 ± 0.164	1.04 ± 1.40	0.689 ± 0.672 (1.09)	-0.427 ± 0.334 (0.638)
Total Uranium, Dissolved (EPA 908.0)	1.09 ± 0.975 (1.86)		0.0564 ± 0.190	1.06 ± 1.50	1.17 ± 0.597 (0.8)	-0.0261 ± 0.301 (0.544)
Total Uranium, Dissolved (HASL-300)						
Total Uranium, Total (HASL-300)						
Uranium-234, Dissolved (HASL-300)						
Uranium-234, Total (HASL-300)						
Uranium-235, Dissolved (HASL-300)						
Uranium-235, Total (HASL-300)						
Uranium-238, Dissolved (HASL-300)						
Uranium-238, Total (HASL-300)						
Radionuclide Act + Unc (MDC) pCi/L (EPA 901.1 Results)[5]						
Actinium-228, Dissolved (EPA 901.1)	-7.120 ± 904 (15.8)		1.48 ± 10.5	-1.558 ± 52.055	-5.263 ± 52.415 (43.25)	-8.630 ± 41.176 (32.31)
Actinium-228, Total (EPA 901.1)	-2.900 ± 21.8 (17.4)		-5.74 ± 648	-10.7996 ± 245.7	-1.515 ± 31.550 (44.23)	-1.608 ± 22.395 (16.88)
Bismuth-212, Dissolved (EPA 901.1)	-13,700 ± 1,880 (63.5)		-6.23 ± 249	53.992 ± 147.880	31.422 ± 63.942 (113.6)	-32.081 ± 104.020 (100.6)
Bismuth-212, Total (EPA 901.1)	2.36 ± 24.7 (45.6)		19.5 ± 44.3	-1.199 ± 81.325	-13.743 ± 549.740 (182.3)	0.934 ± 32.245 (59.15)
Bismuth-214, Dissolved (EPA 901.1)	7.46 ± 7.57 (31.0)		24.2 ± 8.80	2878.9 ± 316.840	50.799 ± 14.979 (15.3)	19.076 ± 13.484 (15.51)
Bismuth-214, Total (EPA 901.1)	6.63 ± 4.49 (34.4)		87.6 ± 16.4	17.264 ± 32.231	186.460 ± 33.504 (19.71)	7.327 ± 6.499 (10.62)
Cesium-134, Dissolved (EPA 901.1)	-0.057 ± 16.7 (4.26)		-0.672 ± 3.45	2.646 ± 90.325	0.000 ± 13.126 (22.55)	-1.511 ± 3.872 (6.565)
Cesium-134, Total (EPA 901.1)	0.444 ± 0.507 (4.60)		-2.09 ± 5.50	-1.574 ± 5.240	1.346 ± 23.514 (39.6)	-1.066 ± 3.278 (5.605)
Cesium-137, Dissolved (EPA 901.1)	-0.232 ± 32.5 (4.00)		-0.209 ± 8.368	-11.315 ± 15.998	-0.105 ± 7.143 (9.56)	0.508 ± 3.702 (6.566)
Cesium-137, Total (EPA 901.1)	-0.560 ± 2.48 (4.30)		-0.205 ± 8.22	0.875 ± 5.086	-0.243 ± 5.802 (9.642)	-0.879 ± 3.976 (4.96)
Lead-212, Dissolved (EPA 901.1)	8.85 ± 15.6 (7.97)		2.31 ± 6.50	-88.256 ± 44.016	2.371 ± 8.658 (15.87)	-6.375 ± 21.764 (14.84)
Lead-212, Total (EPA 901.1)	7.11 ± 10.2 (9.47)		-7.24 ± 43.3	-6.346 ± 211.120	13.493 ± 10.788 (17.79)	4.344 ± 8.188 (9.332)
Lead-214, Dissolved (EPA 901.1)	13.1 ± 19.0 (10.2)		33.5 ± 15.9	2853.2 ± 314.060	49.889 ± 15.466 (20.4)	9.036 ± 9.583 (16.47)
Lead-214, Total (EPA 901.1)	16.1 ± 11.7 (9.92)		76.8 ± 15.4	-3.963 ± 24.352	188.830 ± 34.085 (21.45)	21.217 ± 8.711 (10.12)
Potassium-40, Dissolved (EPA 901.1)	42.0 ± 32.5 (55.2)		111 ± 48.3	38.195 ± 120.260	45.325 ± 76.125 (146)	-32.749 ± 73.738 (114.1)
Potassium-40, Total (EPA 901.1)	19.3 ± 30.5 (58.8)		94.6 ± 50.6	97.208 ± 76.387	16.102 ± 67.685 (140.9)	119.430 ± 36.610 (42.66)
Radium-226, Dissolved (EPA 901.1)	34.6 ± 57.6 (97.3)		-7.11 ± 231	-1.335 ± 343.750	40.459 ± 108.470 (201.6)	126.970 ± 127.850 (163.2)
Radium-226, Total (EPA 901.1)	5.94 ± 58.1 (101)		4.34 ± 88.5	-9.006 ± 117.540	180.910 ± 135.860 (193.4)	-4.145 ± 81.047 (135)
Radium-228, Dissolved (EPA 901.1)	-7.120 ± 904 (15.8)		1.48 ± 10.5	-1.558 ± 52.055	-5.263 ± 52.415 (43.25)	-8.630 ± 41.176 (32.31)
Radium-228, Total (EPA 901.1)	-2.900 ± 21.8 (17.4)		-5.74 ± 648	-10.799 ± 245.760	-1.515 ± 31.550 (44.23)	-1.608 ± 22.395 (16.88)
Thallium-208, Dissolved (EPA 901.1)	2.12 ± 2.46 (4.58)		-0.065 ± 3.70	-3.223 ± 128.930	-2.025 ± 20.895 (10.7)	-0.886 ± 6.943 (8.965)
Thallium-208, Total (EPA 901.1)	-0.301 ± 3.36 (5.23)		-2.03 ± 22.9	-1.618 ± 15.179	-0.294 ± 7.841 (10.27)	2.063 ± 2.103 (5.368)
Thorium-227, Dissolved (EPA 901.1)						
Thorium-227, Total (EPA 901.1)						
Thorium-232, Dissolved (EPA 901.1)	-7.120 ± 904 (15.8)		1.48 ± 10.5	-2154 ± 51946.000	267.070 ± 2983.200 (5328)	591.360 ± 2528.500 (4372)
Thorium-232, Total (EPA 901.1)	-2.900 ± 21.8 (17.4)		-5.74 ± 648	461.14 ± 2681.000	423.750 ± 3507.300 (6138)	1760.700 ± 4250.200 (7296)
Thorium-234, Dissolved (EPA 901.1)	-7.250 ± 453 (777)		334 ± 631	-273.2 ± 1299.400	-14.922 ± 218.470 (308.7)	-19.457 ± 184.230 (252.7)
Thorium-234, Total (EPA 901.1)	253 ± 503 (840)		18.7 ± 1037	-7.505 ± 175.730	1.122 ± 196.560 (348.2)	33.367 ± 270.470 (475)
Uranium-235 (EPA 901.1)	-4.340 ± 22.5 (38.2)		-7.47 ± 91.0	-8.563 ± 137.160	12.897 ± 40.224 (68.86)	-9.698 ± 167.950 (43.18)
Uranium-235, Dissolved (EPA 901.1)	0.360 ± 20.5 (35.4)		1.27 ± 29.4	61.408 ± 111.980	21.278 ± 35.176 (59.57)	-1.196 ± 34.832 (51.23)
Uranium-238 (EPA 901.1)	26.7 ± 31.5 (115)		26 ± 90.4	43.862 ± 80.842	63.211 ± 109.740 (188.1)	57.183 ± 78.272 (130.5)
Uranium-238, Dissolved (EPA 901.1)	3.17 ± 71.6 (125)		-5.15 ± 375	-80.062 ± 1270.300	98.808 ± 96.080 (160.1)	31.516 ± 81.183 (145.2)

Notes:

1.) Act + Unc (MDC) = Activity ± Uncertainty (Minimum Detectable Concentration)

2.) µg/L = micrograms per liter

3.) Each of EPA 901.1, EPA 903.1, EPA 904.0, EPA 908.0, ASTM D5174-97, and HASL-300 are laboratory analysis methods.

4.) Dissolved - Indicates sample filtered with 0.45 micron filter prior to analysis.

5.) pCi/L = picocuries per liter

6.) The EPA 901.1 method results are for non-quantitative purposes only due to the method's high degree of uncertainty.

Exhibit F - Hakes C&D Landfill Leachate Sample Analysis 2012-2017

Parameter	Cell 5 Leachate 11/11/2014	Cell 5 Leachate 5/7/2015	Cell 5 Leachate 11/11/2015	Cell 5 Leachate 5/4/2016	Cell 5 Leachate 11/10/2016	Cell 5 Leachate 6/6/2017
Field Parameters						
Field pH (std. units)	6.83	6.9	6.93	6.87	7.02	6.79
ORP (mV)	7.5	69.4	-126.4	54.2	-21.1	-205.9
Specific Conductivity (us/cm)	5468	6045	6704	6818	6101	6221
Temperature (deg. C)	18.65	23.2	16.03	17.5	20.89	21.9
Turbidity (NTU)	152	171	96.3	88.7	23.4	64.3
Radionuclide Act + Unc (MDC)[1] µg/L[2]						
Total Uranium (ASTM D5174-97)[3]					0.00052 ± 0.032 (0.385)	0.000733 ± 0.034 (0.385)
Total Uranium, Dissolved[4] (ASTM D5174-97)					0.000518 ± 0.034 (0.385)	0.000797 ± 0.036 (0.385)
Radionuclide Act + Unc (MDC) pCi/L[5]						
Radium-226, Dissolved (EPA 903.1)	3.11 ± 1.57 (0.527)	2.67 ± 1.20 (0.954)	2.06 ± 1.15 (1.21)	2.96 ± 0.968 (0.507)	2.19 ± 1.30 (1.24)	0.898 ± 0.933 (1.39)
Radium-226, Total (EPA 903.1)	2.68 ± 1.88 (0.908)	3.14 ± 2.08 (0.945)	0.958 ± 0.712 (0.809)	1.27 ± 1.16 (1.55)	1.2 ± 0.724 (0.793)	1.35 ± 1.30 (1.87)
Radium-228, Dissolved (EPA 904.0)	1.01 ± 0.513 (0.9)	0.681 ± 0.479 (0.933)	1.24 ± 0.541 (0.872)	0.00366 ± 0.308 (0.718)	2.33 ± 0.710 (0.898)	2.42 ± 0.699 (0.785)
Radium-228, Total (EPA 904.0)	3.14 ± 0.942 (1.19)	1.43 ± 0.925 (1.75)	1.66 ± 0.629 (0.956)	2.7 ± 0.770 (0.904)	1.94 ± 0.648 (0.893)	1.32 ± 0.846 (1.64)
Total Uranium (EPA 908.0)	0.334 ± 0.287 (0.45)	0.865 ± 0.360 (0.472)	2.23 ± 0.731 (0.675)	0.239 ± 0.307 (0.555)		
Total Uranium, Dissolved (EPA 908.0)	0.778 ± 0.592 (0.918)	0.636 ± 0.348 (0.512)	2.74 ± 0.853 (0.818)	0.536 ± 0.340 (0.529)		
Total Uranium, Dissolved (HASL-300)						
Total Uranium, Total (HASL-300)						
Uranium-234, Dissolved (HASL-300)						
Uranium-234, Total (HASL-300)						
Uranium-235, Dissolved (HASL-300)						
Uranium-235, Total (HASL-300)						
Uranium-238, Dissolved (HASL-300)						
Uranium-238, Total (HASL-300)						
Radionuclide Act + Unc (MDC) pCi/L (EPA 901.1 Results)[6]						
Actinium-228, Dissolved (EPA 901.1)	-26.581 ± 91.130 (102.7)	0 ± 11.397 (27.86)	5.82 ± 26.105 (34.51)	11.706 ± 14.674 (15.24)	0.496 ± 36.150 (38.58)	11.148 ± 16.458 (16.64)
Actinium-228, Total (EPA 901.1)	-6.837 ± 120.320 (30.58)	1.083 ± 12.233 (13.83)	2.06 ± 13.792 (16.16)	0 ± 14.673 (46.24)	0 ± 12.276 (58.75)	0 ± 7.662 (20.81)
Bismuth-212, Dissolved (EPA 901.1)	-25.026 ± 237.650 (325)	14.857 ± 82.718 (90.45)	0 ± 45.255 (138.3)	17.473 ± 55.120 (61.64)	35.101 ± 108.130 (116.3)	23.217 ± 62.770 (60.75)
Bismuth-212, Total (EPA 901.1)	-20.414 ± 78.455 (107.5)	31.826 ± 39.954 (44.13)	0 ± 13.461 (74.22)	0 ± 40.028 (142.4)	31.06 ± 106.960 (122.1)	0 ± 30.517 (67.34)
Bismuth-214, Dissolved (EPA 901.1)	6221.7 ± 670.090 (57.08)	512.4 ± 60.088 (16.65)	22.554 ± 13.425 (16.62)	75.469 ± 14.748 (9.911)	595.81 ± 71.039 (25.89)	15.948 ± 9.449 (8.905)
Bismuth-214, Total (EPA 901.1)	-0.226 ± 9.291 (15.45)	7.984 ± 12.612 (14.53)	49.436 ± 12.938 (10.31)	0 ± 10.770 (28.05)	347.44 ± 53.241 (23.93)	40.987 ± 11.091 (8.763)
Cesium-134, Dissolved (EPA 901.1)	18.583 ± 122.550 (202.5)	0 ± 2.735 (8.447)	0.194 ± 8.158 (9.562)	-0.043 ± 4.463 (5.079)	4.488 ± 7.851 (12.69)	2.276 ± 4.549 (4.221)
Cesium-134, Total (EPA 901.1)	0.018 ± 3.795 (6.95)	1.316 ± 4.284 (4.693)	1.664 ± 3.820 (4.274)	-0.284 ± 7.800 (9.166)	0 ± 5.376 (12.68)	1.467 ± 3.817 (4.083)
Cesium-137, Dissolved (EPA 901.1)	-23.293 ± 21.840 (35.49)	1.25 ± 6.216 (6.728)	2.304 ± 6.721 (7.782)	0 ± 0.862 (7.693)	0 ± 4.131 (11.41)	0.274 ± 4.280 (4.579)
Cesium-137, Total (EPA 901.1)	0 ± 4.798 (8.73)	0.228 ± 4.257 (4.759)	-1.27 ± 5.364 (5.835)	-3.126 ± 10.186 (11.63)	0.457 ± 10.815 (12.48)	-0.102 ± 4.476 (4.993)
Lead-212, Dissolved (EPA 901.1)	1205.7 ± 187.920 (162.1)	97.904 ± 29.589 (16.92)	0 ± 7.831 (19.9)	10.932 ± 18.133 (11.31)	195.89 ± 56.662 (23.86)	1.188 ± 5.691 (8.065)
Lead-212, Total (EPA 901.1)	-1.043 ± 16.385 (12.77)	0 ± 3.950 (9.473)	0 ± 2.824 (10.1)	2.944 ± 15.715 (19.37)	73.833 ± 33.325 (27.92)	7.976 ± 14.760 (10.29)
Lead-214, Dissolved (EPA 901.1)	6818.9 ± 738.230 (73.28)	581.9 ± 69.012 (18.43)	14.916 ± 17.730 (21.63)	75.215 ± 14.380 (9.459)	713.27 ± 85.748 (25.99)	8.424 ± 8.783 (9.561)
Lead-214, Total (EPA 901.1)	11.765 ± 7.949 (10.42)	3.255 ± 9.484 (11.43)	37.508 ± 11.916 (9.788)	11.896 ± 17.951 (22.21)	345.25 ± 51.096 (24.26)	31.945 ± 11.578 (10.13)
Potassium-40, Dissolved (EPA 901.1)	49.679 ± 149.290 (255.1)	39.745 ± 91.876 (91.06)	186.83 ± 109.530 (124)	150.28 ± 55.673 (53.17)	82.309 ± 109.210 (108)	110.43 ± 53.662 (50.04)
Potassium-40, Total (EPA 901.1)	22.019 ± 50.369 (96.66)	76.459 ± 54.759 (57.36)	56.529 ± 75.814 (75.48)	0 ± 69.751 (181.8)	46.882 ± 159.440 (181.5)	132.78 ± 49.874 (46.86)
Radium-226, Dissolved (EPA 901.1)	37.208 ± 567.340 (947.8)	0 ± 110.660 (218.8)	10.972 ± 141.870 (188.3)	97.244 ± 109.150 (128.9)	0 ± 192.880 (291.8)	12.579 ± 103.520 (119.4)
Radium-226, Total (EPA 901.1)	22.673 ± 97.209 (160.2)	41.083 ± 70.324 (100.6)	39.43 ± 91.210 (113.3)	0 ± 139.040 (263)	133.98 ± 195.550 (236.6)	18.509 ± 98.768 (124.1)
Radium-228, Dissolved (EPA 901.1)	-26.581 ± 91.130 (102.7)	0 ± 11.397 (27.86)	5.82 ± 26.105 (34.51)	11.706 ± 14.674 (15.24)	0.496 ± 36.150 (38.58)	11.148 ± 16.458 (16.64)
Radium-228, Total (EPA 901.1)	-6.837 ± 120.320 (30.58)	1.083 ± 12.233 (13.83)	2.06 ± 13.792 (16.16)	0 ± 14.673 (46.24)	0 ± 12.276 (58.75)	0 ± 7.662 (20.81)
Thallium-208, Dissolved (EPA 901.1)	-12.905 ± 21.692 (30.66)	0.499 ± 6.336 (7.213)	0 ± 5.558 (12.52)	2.77 ± 3.703 (5.861)	3.648 ± 8.159 (9.008)	1.525 ± 4.526 (4.652)
Thallium-208, Total (EPA 901.1)	-1.255 ± 38.779 (7.649)	0 ± 2.277 (4.518)	0 ± 1.102 (5.292)	0 ± 1.887 (12.82)	0 ± 6.257 (13)	0 ± 2.190 (6.381)
Thorium-227, Dissolved (EPA 901.1)						
Thorium-227, Total (EPA 901.1)						
Thorium-232, Dissolved (EPA 901.1)	-10170 ± 41412.000 (56830)	0 ± 6564.500 (14200)	1184 ± 4262.300 (5269)	6190 ± 7584.700 (9106)	6861.1 ± 15847.000 (19150)	4675.1 ± 4366.500 (7076)
Thorium-232, Total (EPA 901.1)	-981.84 ± 39274.000 (14230)	2723.6 ± 6705.300 (8284)	0 ± 3686.200 (9737)	2741 ± 4616.100 (5607)	-162.19 ± 6157.400 (7585)	-2397 ± 8099.700 (9950)
Thorium-234, Dissolved (EPA 901.1)	1225.5 ± 1564.500 (2572)	94.097 ± 602.680 (757.1)	0 ± 142.200 (348.3)	47.94 ± 441.450 (560.8)	345.91 ± 860.080 (1070)	96.497 ± 139.230 (414.4)
Thorium-234, Total (EPA 901.1)	124.82 ± 138.410 (638.6)	167.6 ± 357.650 (452.2)	0 ± 212.310 (559.1)	4.114 ± 269.030 (341.5)	15.067 ± 335.640 (418.4)	0 ± 212.310 (505.7)
Uranium-235 (EPA 901.1)	-12.206 ± 87.172 (46.67)	12.604 ± 27.105 (33.66)				
Uranium-235, Dissolved (EPA 901.1)	-97.448 ± 219.760 (316.6)	24.599 ± 55.125 (66.92)				
Uranium-238 (EPA 901.1)	64.726 ± 90.801 (159.4)	0 ± 57.889 (128.1)				
Uranium-238, Dissolved (EPA 901.1)	-402.38 ± 650.120 (849.1)	0 ± 99.555 (218)				

Notes:

1.) Act + Unc (MDC) = Activity ± Uncertainty (Minimum Detectable Concentration)

2.) µg/L = micrograms per liter

3.) Each of EPA 901.1, EPA 903.1, EPA 904.0, EPA 908.0, ASTM D5174-97, and HASL-300 are laboratory analysis methods.

4.) Dissolved - Indicates sample filtered with 0.45 micron filter prior to analysis.

5.) pCi/L = picocuries per liter

6.) The EPA 901.1 method results are for non-quantitative purposes only due to the method's high degree of uncertainty.

Exhibit F - Hakes C&D Landfill Leachate Sample Analysis 2012-2017

Parameter	Cell 5 Leachate 11/17/2017	Cell 6 Leachate 5/23/2012	Cell 6 Leachate 12/4/2012	Cell 6 Leachate 5/15/2013	Cell 6 Leachate 11/6/2013	Cell 6 Leachate 5/15/2014
Field Parameters						
Field pH (std. units)	6.88	7.02	6.94	6.8	6.5	6.45
ORP (mV)	-102.1	146.7	2.6	-224.9	-109.7	-97.7
Specific Conductivity (us/cm)	6278	7202	14553	13320	10784	9527
Temperature (deg. C)	16.2	22.06	23.09	22.31	17.52	23.33
Turbidity (NTU)	41.6	32.6	93.8	32.9	51.1	211
Radionuclide Act + Unc (MDC)[1] µg/L[2]						
Total Uranium (ASTM D5174-97)[3]						
Total Uranium, Dissolved[4] (ASTM D5174-97)						
Radionuclide Act + Unc (MDC) pCi/L[5]						
Radium-226, Dissolved (EPA 903.1)	1.07 ± 0.36 (0.16)	1.19 ± 0.582 (0.501)	5.74 ± 1.66	4.18 ± 1.81	1.24 ± 0.999 (1.24)	2.47 ± 1.18 (1.2)
Radium-226, Total (EPA 903.1)	1.07 ± 0.36 (0.19)	1.97 ± 0.767 (0.162)	5.6 ± 2.66	3.31 ± 1.70	1.28 ± 1.47 (0.87)	1.30 ± 1.20 (1.51)
Radium-228, Dissolved (EPA 904.0)	1.85 ± 0.57 (0.61)	0.810 ± 0.515 (0.956)	3.87 ± 0.991	1.87 ± 0.662	2.71 ± 1.02 (1.5)	1.64 ± 0.590 (0.858)
Radium-228, Total (EPA 904.0)	1.07 ± 0.46 (0.75)	1.56 ± 0.604 (0.925)	5.84 ± 2.51	2.73 ± 1.45	1.72 ± 1.30 (2.26)	0.960 ± 0.534 (0.959)
Total Uranium (EPA 908.0)		0.0510 ± 0.793 (1.86)	0.0671 ± 0.140	1.27 ± 1.33	0.866 ± 0.531 (0.773)	-0.0546 ± 0.262 (0.486)
Total Uranium, Dissolved (EPA 908.0)		-0.233 ± 0.739 (1.87)	0.178 ± 0.154	1.34 ± 1.42	0.693 ± 0.216 (0.205)	0.196 ± 0.306 (0.518)
Total Uranium, Dissolved (HASL-300)	0.75 ± 0.2 (0.1)					
Total Uranium, Total (HASL-300)	0.82 ± 0.26 (0.15)					
Uranium-234, Dissolved (HASL-300)	0.45 ± 0.16 (0.1)					
Uranium-234, Total (HASL-300)	0.47 ± 0.19 (0.13)					
Uranium-235, Dissolved (HASL-300)	0.036 ± 0.046 (0.035)					
Uranium-235, Total (HASL-300)	0.023 ± 0.067 (0.121)					
Uranium-238, Dissolved (HASL-300)	0.26 ± 0.11 (0.03)					
Uranium-238, Total (HASL-300)	0.33 ± 0.15 (0.04)					
Radionuclide Act + Unc (MDC) pCi/L (EPA 901.1 Results)[6]						
Actinium-228, Dissolved (EPA 901.1)	17 ± 14 (22)	-30,200 ± 39.3 (53.6)	6.35 ± 14.4	-4,078 ± 32,606	-6,774 ± 88,042 (50.24)	-0.333 ± 18.778 (33.97)
Actinium-228, Total (EPA 901.1)	37 ± 17 (25)	5.36 ± 42.7 (48.8)	9.2 ± 16.6	-6,921 ± 73,925	3,731 ± 23,437 (44.29)	4,435 ± 10,110 (18.06)
Bismuth-212, Dissolved (EPA 901.1)	68 ± 48 (75)	105 ± 115 (200)	15.9 ± 48.9	1,482 ± 62,670	-7,919 ± 316,740 (163.8)	3,567 ± 57,097 (104.2)
Bismuth-212, Total (EPA 901.1)	31 ± 59 (99)	1.46 ± 101 (176)	22 ± 56.4	-0.63 ± 85,341	-38,698 ± 188,190 (163.9)	-2,533 ± 101,300 (72.9)
Bismuth-214, Dissolved (EPA 901.1)	-3 ± 12 (20)	1,870 ± 108 (103)	-6.78 ± 118	-6,882 ± 42,477	537,350 ± 70,694 (19.97)	2,008 ± 10,721 (18.36)
Bismuth-214, Total (EPA 901.1)	14.1 ± 8.9 (13.9)	43.2 ± 38.4 (95.4)	-23.9 ± 144	166.5 ± 29,290	450,210 ± 63,878 (27.69)	46,389 ± 12,358 (10.1)
Cesium-134, Dissolved (EPA 901.1)	-2.9 ± 3.1 (5.5)	6.82 ± 8.92 (13.3)	-1.22 ± 4.93	-1,779 ± 5,252	1,349 ± 41,714 (69.61)	0.057 ± 4.522 (7.902)
Cesium-134, Total (EPA 901.1)	-1.8 ± 4.2 (7.3)	-3,310 ± 7.74 (12.6)	-1.28 ± 4.12	2,351 ± 3,694	-2,014 ± 35,919 (60.04)	-2.557 ± 4.148 (6.901)
Cesium-137, Dissolved (EPA 901.1)	0.8 ± 2.9 (4.9)	-2,220 ± 9.76 (13.9)	1.8 ± 3.67	-0.209 ± 20,920	-2,554 ± 13,479 (14.74)	-0.026 ± 4.187 (7.425)
Cesium-137, Total (EPA 901.1)	0.3 ± 4.3 (7.3)	-6,710 ± 7.62 (12.8)	-0.943 ± 6.21	-2,479 ± 8,102	0.271 ± 6.598 (11.92)	-0.088 ± 10.733 (5.12)
Lead-212, Dissolved (EPA 901.1)	-0.1 ± 6.9 (11.6)	-1,910 ± 16.9 (24.7)	-4.41 ± 233	-6,801 ± 93,396	75,475 ± 22,164 (23.09)	4.018 ± 10.403 (14.08)
Lead-212, Total (EPA 901.1)	0 ± 10 (17)	6.36 ± 18.3 (22.5)	-1.83 ± 19.3	26,725 ± 15,570	57,948 ± 18,576 (27.5)	0.329 ± 5.473 (9.839)
Lead-214, Dissolved (EPA 901.1)	8.8 ± 6.1 (9.6)	1,910 ± 144 (28.9)	8.53 ± 9.80	8,682 ± 8,606	563,230 ± 72,309 (24.69)	1,701 ± 9,521 (17.36)
Lead-214, Total (EPA 901.1)	-4 ± 12 (21)	24.9 ± 15.2 (27.4)	3.52 ± 10.2	189.33 ± 28,610	432,490 ± 59,577 (25.03)	27,287 ± 14,016 (12.68)
Potassium-40, Dissolved (EPA 901.1)	67 ± 75 (123)	61.0 ± 135 (195)	67.4 ± 69.7	185.06 ± 102,490	299,730 ± 96,482 (106.7)	41,610 ± 62,411 (124.8)
Potassium-40, Total (EPA 901.1)	80 ± 100 (170)	-35,900 ± 139 (213)	254 ± 92.1	92,937 ± 83,848	59,664 ± 86,218 (159.3)	102,020 ± 45,390 (52.27)
Radium-226, Dissolved (EPA 901.1)	-1 ± 71 (118)	-93,300 ± 247 (350)	37.7 ± 79.4	29,396 ± 109,850	1,854 ± 186,260 (326)	-10,793 ± 107,810 (162.5)
Radium-226, Total (EPA 901.1)	-10 ± 100 (170)	-55,100 ± 214 (281)	-2.36 ± 94.2	40,06 ± 122,330	61,980 ± 161,570 (284.9)	81,405 ± 89,399 (118.9)
Radium-228, Dissolved (EPA 901.1)	17 ± 14 (22)	-30,200 ± 39.3 (53.6)	6.35 ± 14.4	-4,078 ± 32,606	-6,774 ± 88,042 (50.24)	-0.333 ± 18.778 (33.97)
Radium-228, Total (EPA 901.1)	37 ± 17 (25)	5.36 ± 42.7 (48.8)	9.2 ± 16.6	-6,921 ± 73,925	3,731 ± 23,437 (44.29)	4,435 ± 10,110 (18.06)
Thallium-208, Dissolved (EPA 901.1)	-0.1 ± 4.8 (8.1)	-6,460 ± 11.5 (15.1)	0.98 ± 4.22	-0.741 ± 6,759	-1,581 ± 16,329 (11.65)	-2,271 ± 9,513 (8,781)
Thallium-208, Total (EPA 901.1)	6.6 ± 4.2 (6.6)	-0,295 ± 12.2 (14.5)	-2.61 ± 129	-2,693 ± 46,305	1,912 ± 6,620 (11.87)	1,768 ± 1,640 (5,327)
Thorium-227, Dissolved (EPA 901.1)	-2 ± 20 (33)					
Thorium-227, Total (EPA 901.1)	10 ± 30 (49)					
Thorium-232, Dissolved (EPA 901.1)	17 ± 14 (22)	-30,200 ± 39.3 (53.6)	6.35 ± 14.4	595.51 ± 2727.700	511,900 ± 4679.000 (8051)	998,600 ± 2692.300 (4706)
Thorium-232, Total (EPA 901.1)	37 ± 17 (25)	5.36 ± 42.7 (48.8)	9.2 ± 16.6	349.91 ± 3328.000	[illegible]	157,210 ± 5971.500 (10320)
Thorium-234, Dissolved (EPA 901.1)	38 ± 40 (76)	196 ± 234 (380)	247 ± 667	-54.779 ± 449.200	-16,941 ± 355,100 (463.6)	145,120 ± 128,140 (196.7)
Thorium-234, Total (EPA 901.1)	69 ± 81 (138)	399 ± 471 (759)	277 ± 759	1,299 ± 198,230	-68,843 ± 1176,300 (439)	33,911 ± 333,570 (576)
Uranium-235 (EPA 901.1)		27.2 ± 47.2 (73.7)	0.502 ± 31.1	-29,946 ± 59,449	-22,747 ± 79,996 (86.53)	-11,969 ± 95,260 (41.55)
Uranium-235, Dissolved (EPA 901.1)		1.77 ± 53.9 (87.0)	-2.73 ± 307	8,328 ± 31,446	-24,889 ± 93,288 (88.56)	-4,231 ± 46,216 (56.43)
Uranium-238 (EPA 901.1)		289 ± 1,210 (2,070)	0.382 ± 85.1	85,842 ± 95,919	38,315 ± 139,950 (233.3)	55,661 ± 75,356 (125.7)
Uranium-238, Dissolved (EPA 901.1)		-1,060,000 ± 1,730 (2,390)	-30 ± 129	54,16 ± 82,463	-41,734 ± 2030,000 (259,700)	36,295 ± 89,703 (159.9)

Notes:

1.) Act + Unc (MDC) = Activity ± Uncertainty (Minimum Detectable Concentration)

2.) µg/L = micrograms per liter

3.) Each of EPA 901.1, EPA 903.1, EPA 904.0, EPA 908.0, ASTM D5174-97, and HASL-300 are laboratory analysis methods.

4.) Dissolved - Indicates sample filtered with 0.45 micron filter prior to analysis.

5.) pCi/L = picocuries per liter

6.) The EPA 901.1 method results are for non-quantitative purposes only due to the method's high degree of uncertainty.

Exhibit F - Hakes C&D Landfill Leachate Sample Analysis 2012-2017

Parameter	Cell 6 Leachate 11/11/2014	Cell 6 Leachate 5/7/2015	Cell 6 Leachate 11/11/2015	Cell 6 Leachate 5/4/2016	Cell 6 Leachate 11/18/2016	Cell 6 Leachate 5/6/2017
Field Parameters						
Field pH (std. units)	6.61	6.82	6.97	6.96	7.13	6.84
ORP (mV)	-163.6	-154.8	-107.2	-166.5	-222.1	-291.7
Specific Conductivity (us/cm)	11981	11856	10151	10908	9087	12178
Temperature (deg. C)	22.17	26.5	17.73	21.1	24.05	24.6
Turbidity (NTU)	185	85.2	80.5	41.8	60.2	67.4
Radionuclide Act + Unc (MDC)[1] µg/L[2]						
Total Uranium (ASTM D5174-97)[3]					0.00062 ± 0.026 (0.385)	0.00112 ± 0.039 (0.385)
Total Uranium, Dissolved[4] (ASTM D5174-97)					0.000732 ± 0.032 (0.385)	0.00105 ± 0.047 (0.385)
Radionuclide Act + Unc (MDC) pCi/L[5]						
Radium-226, Dissolved (EPA 903.1)	1.71 ± 0.985 (0.966)	2.22 ± 1.12 (0.978)	2.7 ± 0.985 (0.228)	0.888 ± 0.642 (0.895)	0.762 ± 0.533 (0.643)	2.34 ± 1.21 (1.01)
Radium-226, Total (EPA 903.1)	1.4 ± 1.68 (0.946)	3.5 ± 2.21 (0.948)	0.984 ± 0.796 (0.985)	1.83 ± 1.02 (0.977)	0.675 ± 0.536 (0.696)	2.75 ± 1.80 (1.84)
Radium-228, Dissolved (EPA 904.0)	2.01 ± 0.674 (0.912)	1.49 ± 0.524 (0.738)	1.64 ± 0.596 (0.857)	0.957 ± 0.482 (0.86)	1.44 ± 0.569 (0.897)	2.07 ± 0.649 (0.807)
Radium-228, Total (EPA 904.0)	3.57 ± 1.29 (1.84)	1.49 ± 0.817 (1.49)	2.09 ± 0.652 (0.78)	3.27 ± 0.866 (0.879)	0.631 ± 0.409 (0.767)	2.4 ± 1.04 (1.77)
Total Uranium (EPA 908.0)	0.0554 ± 0.380 (0.669)	0.918 ± 0.383 (0.512)	2.59 ± 0.805 (0.736)	0.262 ± 0.325 (0.585)		
Total Uranium, Dissolved (EPA 908.0)	-0.084 ± 0.267 (0.498)	1.59 ± 0.515 (0.595)	0.536 ± 0.602 (1.07)	0.742 ± 0.450 (0.716)		
Total Uranium, Dissolved (HASL-300)						
Total Uranium, Total (HASL-300)						
Uranium-234, Dissolved (HASL-300)						
Uranium-234, Total (HASL-300)						
Uranium-235, Dissolved (HASL-300)						
Uranium-235, Total (HASL-300)						
Uranium-238, Dissolved (HASL-300)						
Uranium-238, Total (HASL-300)						
Radionuclide Act + Unc (MDC) pCi/L (EPA 901.1 Results)[6]						
Actinium-228, Dissolved (EPA 901.1)	9.886 ± 30.538 (59.54)	2.209 ± 26.309 (35.64)	9.101 ± 26.524 (34.51)	8.192 ± 14.364 (15.24)	0 ± 8.469 (48.02)	0 ± 15.628 (36.2)
Actinium-228, Total (EPA 901.1)	10.409 ± 24.611 (48.16)	0 ± 17.356 (39.31)	11.14 ± 9.835 (11.8)	17.4 ± 28.767 (36.33)	0.39 ± 14.166 (17.1)	3.444 ± 16.759 (18.84)
Bismuth-212, Dissolved (EPA 901.1)	-11.62 ± 464.800 (94.07)	21.182 ± 101.920 (121.1)	22.897 ± 94.957 (113)	0 ± 33.494 (71.72)	-4.793 ± 137.760 (152)	0 ± 39.348 (126.7)
Bismuth-212, Total (EPA 901.1)	-10.516 ± 420.640 (185.4)	20.202 ± 66.761 (106.9)	36.732 ± 52.851 (57.12)	0 ± 32.683 (142.4)	20.552 ± 57.388 (62.98)	28.15 ± 56.478 (60.37)
Bismuth-214, Dissolved (EPA 901.1)	-10.736 ± 429.430 (35.06)	0 ± 9.455 (24.41)	36.899 ± 16.695 (18.42)	107.45 ± 17.701 (9.759)	17.385 ± 25.432 (27.25)	411.44 ± 51.257 (18.35)
Bismuth-214, Total (EPA 901.1)	-4.361 ± 29.908 (27.92)	17.718 ± 16.357 (20.19)	17.557 ± 11.768 (12.09)	74.751 ± 23.569 (22.52)	5.86 ± 10.509 (11.96)	8.261 ± 9.579 (12.72)
Cesium-134, Dissolved (EPA 901.1)	-1.931 ± 9.353 (16.93)	0 ± 2.159 (9.734)	1.105 ± 7.107 (8.353)	0.325 ± 0.481 (5.767)	4.806 ± 4.715 (11.28)	0 ± 3.379 (9.98)
Cesium-134, Total (EPA 901.1)	-1.461 ± 6.674 (12.34)	3.922 ± 5.602 (6.314)	-2.506 ± 5.363 (5.699)	2.219 ± 8.990 (10.27)	0.827 ± 4.805 (5.276)	0 ± 0.965 (5.21)
Cesium-137, Dissolved (EPA 901.1)	-0.221 ± 8.829 (13.7)	12.23 ± 4.646 (3.005)	2.236 ± 5.722 (6.649)	0 ± 1.927 (5.685)	-5.004 ± 11.852 (12.68)	0 ± 1.039 (10.47)
Cesium-137, Total (EPA 901.1)	-0.2 ± 7.990 (6.009)	0 ± 4.314 (10.22)	-1.041 ± 5.884 (6.387)	3.194 ± 8.180 (9.422)	1.168 ± 4.088 (4.511)	1.041 ± 3.624 (4.245)
Lead-212, Dissolved (EPA 901.1)	-6.937 ± 214.460 (26.04)	0 ± 7.231 (19.23)	0 ± 8.756 (15.99)	16.584 ± 16.533 (11.54)	4.077 ± 15.882 (19.13)	10.857 ± 9.656 (14.8)
Lead-212, Total (EPA 901.1)	2.106 ± 11.720 (22.55)	0 ± 8.957 (19.51)	5.1 ± 6.860 (8.35)	0 ± 9.036 (22.42)	0 ± 4.170 (10.73)	3.325 ± 7.019 (6.608)
Lead-214, Dissolved (EPA 901.1)	8.47 ± 15.521 (28.85)	3.229 ± 15.459 (20.61)	32.969 ± 14.911 (19.87)	112.21 ± 18.663 (10.9)	34.098 ± 19.097 (21.01)	442.99 ± 53.175 (19.81)
Lead-214, Total (EPA 901.1)	-0.068 ± 11.656 (24.3)	0.371 ± 16.012 (23.54)	22.521 ± 8.520 (8.884)	99.876 ± 26.198 (21.36)	11.224 ± 10.300 (10.35)	1.957 ± 8.850 (10.7)
Potassium-40, Dissolved (EPA 901.1)	79.214 ± 127.930 (249)	133.1 ± 122.860 (143.1)	134.97 ± 121.320 (139.4)	194.11 ± 50.952 (43.07)	204.34 ± 100.750 (109.1)	266.49 ± 95.889 (93.96)
Potassium-40, Total (EPA 901.1)	109.74 ± 112.200 (206.1)	87.842 ± 118.150 (143.1)	179.64 ± 47.476 (39.08)	209.21 ± 96.525 (114)	133.77 ± 52.140 (53.62)	216.58 ± 52.598 (40.14)
Radium-226, Dissolved (EPA 901.1)	146.1 ± 127.750 (212.1)	31.131 ± 147.760 (193.9)	0 ± 96.462 (224.9)	112.13 ± 124.210 (142.6)	56.923 ± 204.080 (257)	0 ± 110.140 (207.1)
Radium-226, Total (EPA 901.1)	116.87 ± 148.630 (264.7)	192.61 ± 117.300 (148.7)	25.29 ± 101.430 (125.4)	0 ± 70.798 (237.6)	36.26 ± 99.458 (124.1)	8.462 ± 102.230 (128.4)
Radium-228, Dissolved (EPA 901.1)	9.886 ± 30.538 (59.54)	2.209 ± 26.309 (35.64)	9.101 ± 26.524 (34.51)	8.192 ± 14.364 (15.24)	0 ± 8.469 (48.02)	0 ± 15.628 (36.2)
Radium-228, Total (EPA 901.1)	10.409 ± 24.611 (48.16)	0 ± 17.356 (39.31)	11.14 ± 9.835 (11.8)	17.4 ± 28.767 (36.33)	0.39 ± 14.166 (17.1)	3.444 ± 16.759 (18.84)
Thallium-208, Dissolved (EPA 901.1)	-5.66 ± 63.906 (18.47)	0 ± 4.991 (12.65)	0 ± 3.930 (10.11)	3.668 ± 6.273 (5.661)	0 ± 4.822 (12.9)	0 ± 6.558 (11.15)
Thallium-208, Total (EPA 901.1)	-0.017 ± 7.625 (15.8)	0 ± 4.487 (11.52)	2.568 ± 3.895 (4.489)	0 ± 2.882 (12.28)	4.871 ± 4.898 (4.409)	0.412 ± 4.491 (5.228)
Thorium-227, Dissolved (EPA 901.1)						
Thorium-227, Total (EPA 901.1)						
Thorium-232, Dissolved (EPA 901.1)	-811.94 ± 11917.000 (7399)	535.22 ± 4031.900 (5031)	859.6 ± 4436.100 (5497)	921.92 ± 7622.700 (9453)	12222 ± 15484.000 (18540)	2714 ± 4543.300 (5446)
Thorium-232, Total (EPA 901.1)	927.75 ± 4090.100 (7345)	1297.5 ± 4019.600 (4969)	0 ± 4097.000 (9226)	2805.9 ± 4794.100 (5821)	2355.3 ± 6995.900 (8633)	3529.6 ± 6603.800 (8070)
Thorium-234, Dissolved (EPA 901.1)	-59.642 ± 772.250 (421.9)	0 ± 125.090 (298.1)	0 ± 112.960 (319.2)	0 ± 187.510 (551.7)	198.05 ± 909.930 (1156)	11.694 ± 258.590 (314.3)
Thorium-234, Total (EPA 901.1)	31.213 ± 234.030 (425.2)	72.665 ± 219.270 (277.7)	87.586 ± 160.400 (486.8)	0 ± 190.660 (363.4)	88.555 ± 378.210 (486)	0 ± 238.760 (515.5)
Uranium-235 (EPA 901.1)	0.845 ± 29.212 (57.04)	0 ± 14.819 (58.33)				
Uranium-235, Dissolved (EPA 901.1)	-19.512 ± 147.980 (99.7)	16.188 ± 41.178 (50.54)				
Uranium-238 (EPA 901.1)	50.771 ± 132.180 (234.5)	84.974 ± 126.500 (161)				
Uranium-238, Dissolved (EPA 901.1)	75.716 ± 137.740 (242.3)	0 ± 84.714 (164.4)				

Notes:

1.) Act + Unc (MDC) = Activity ± Uncertainty (Minimum Detectable Concentration)

2.) µg/L = micrograms per liter

3.) Each of EPA 901.1, EPA 903.1, EPA 904.0, EPA 908.0, ASTM D5174-97, and HASL-300 are laboratory analysis methods.

4.) Dissolved - Indicates sample filtered with 0.45 micron filter prior to analysis.

5.) pCi/L = picocuries per liter

6.) The EPA 901.1 method results are for non-quantitative purposes only due to the method's high degree of uncertainty.

Exhibit F - Hakes C&D Landfill Leachate Sample Analysis 2012-2017

Parameter	Cell 8 Leachate 11/17/2017	Cell 8 Leachate 5/4/2016	Cell 8 Leachate 11/18/2016	Cell 8 Leachate 6/6/2017	Cell 8 Leachate 11/17/2017
Field Parameters					
Field pH (std. units)	6.97	6.45	6.55	6.74	6.62
ORP (mV)	-239.1	-153.5	73.6	-257.4	-13.5
Specific Conductivity (us/cm)	10151	2785	1220	5306	2286
Temperature (deg. C)	19.2	17.6	6.08	22	14
Turbidity (NTU)	107	175	35.4	38.4	140
Radionuclide Act + Unc (MDC)[1] µg/L[2]					
Total Uranium (ASTM D5174-97)[3]			0.000612 ± 0.026 (0.385)	0.000866 ± 0.046 (0.385)	
Total Uranium, Dissolved[4] (ASTM D5174-97)			0.000649 ± 0.024 (0.385)	0.000911 ± 0.047 (0.385)	
Radionuclide Act + Unc (MDC) pCi/L[5]					
Radium-226, Dissolved (EPA 903.1)	2.77 ± 0.78 (0.19)	1.13 ± 0.622 (0.554)	0.233 ± 0.355 (0.21)	1.51 ± 1.00 (0.455)	0.88 ± 0.31 (0.16)
Radium-226, Total (EPA 903.1)	1.81 ± 0.53 (0.12)	0.211 ± 0.774 (1.27)	0.0769 ± 0.351 (0.208)	2.43 ± 2.24 (1.32)	1.38 ± 0.45 (0.18)
Radium-228, Dissolved (EPA 904.0)	3.1 ± 0.84 (0.62)	0.669 ± 0.465 (0.897)	0.585 ± 0.461 (0.918)	1.65 ± 0.611 (0.89)	1.38 ± 0.51 (0.72)
Radium-228, Total (EPA 904.0)	1.18 ± 0.46 (0.7)	0.732 ± 0.475 (0.905)	0.27 ± 0.378 (0.801)	1.77 ± 1.34 (2.7)	1.46 ± 0.54 (0.79)
Total Uranium (EPA 908.0)		0.856 ± 0.445 (0.662)			
Total Uranium, Dissolved (EPA 908.0)		1.48 ± 0.518 (0.588)			
Total Uranium, Dissolved (HASL-300)	0.32 ± 0.13 (0.09)				0.59 ± 0.21 (0.16)
Total Uranium, Total (HASL-300)	0.25 ± 0.19 (0.23)				0.65 ± 0.18 (0.12)
Uranium-234, Dissolved (HASL-300)	0.192 ± 0.097 (0.07)				0.3 ± 0.15 (0.13)
Uranium-234, Total (HASL-300)	0.2 ± 0.14 (0.15)				0.39 ± 0.14 (0.09)
Uranium-235, Dissolved (HASL-300)	0.012 ± 0.045 (0.033)				0.022 ± 0.064 (0.115)
Uranium-235, Total (HASL-300)	-0.017 ± 0.087 (0.157)				0.021 ± 0.041 (0.083)
Uranium-238, Dissolved (HASL-300)	0.118 ± 0.076 (0.07)				0.27 ± 0.14 (0.08)
Uranium-238, Total (HASL-300)	0.064 ± 0.096 (0.179)				0.24 ± 0.11 (0.07)
Radionuclide Act + Unc (MDC) pCi/L (EPA 901.1 Results)[6]					
Actinium-228, Dissolved (EPA 901.1)	4.8 ± 9.1 (19.5)	0.448 ± 34.301 (43.22)	47.093 ± 73.980 (76.54)	12.267 ± 9.673 (19.95)	4 ± 25 (43)
Actinium-228, Total (EPA 901.1)	15 ± 19 (30)	0 ± 15.389 (54.22)	4.586 ± 15.790 (18.22)	6.953 ± 102.350 (110.6)	-3 ± 11 (19)
Bismuth-212, Dissolved (EPA 901.1)	-7 ± 49 (82)	23.229 ± 129.950 (152.9)	0 ± 142.110 (286)	0 ± 26.514 (75.19)	5 ± 49 (84)
Bismuth-212, Total (EPA 901.1)	36 ± 94 (157)	0 ± 73.084 (171.8)	31.516 ± 94.776 (59.23)	0 ± 81.230 (391.1)	-16 ± 49 (82)
Bismuth-214, Dissolved (EPA 901.1)	-7.6 ± 9.5 (15.8)	0 ± 9.677 (28.89)	3779.3 ± 407.970 (48.82)	113.23 ± 18.794 (12.43)	-3 ± 14 (24)
Bismuth-214, Total (EPA 901.1)	9.3 ± 9.7 (15.8)	0 ± 12.206 (26.3)	10.19 ± 11.736 (12.56)	6067.2 ± 653.720 (70.33)	-10.8 ± 9.6 (15.9)
Cesium-134, Dissolved (EPA 901.1)	-1.7 ± 2 (3.5)	0.569 ± 9.337 (10.78)	0 ± 7.265 (22.76)	1.167 ± 5.520 (5.334)	-0.5 ± 5.8 (9.8)
Cesium-134, Total (EPA 901.1)	-3.9 ± 4.9 (8.6)	-3.016 ± 10.794 (12.16)	0 ± 1.553 (5.413)	2.72 ± 24.998 (27.3)	-2.6 ± 2.1 (3.6)
Cesium-137, Dissolved (EPA 901.1)	-2 ± 1.8 (3.2)	-1.427 ± 10.640 (12.26)	0 ± 5.201 (23.21)	-3.479 ± 5.542 (5.783)	1.1 ± 3.6 (6)
Cesium-137, Total (EPA 901.1)	1.6 ± 4.8 (8.1)	7.067 ± 6.059 (6.365)	0.863 ± 4.064 (4.511)	0 ± 15.721 (32.75)	-1.7 ± 1.8 (3.2)
Lead-212, Dissolved (EPA 901.1)	-0.4 ± 5.5 (9.1)	10.6 ± 14.194 (17.14)	1005.6 ± 123.520 (41.77)	37.763 ± 15.140 (9.644)	0 ± 10 (17)
Lead-212, Total (EPA 901.1)	12.9 ± 6.2 (9.4)	2.013 ± 16.195 (19.96)	0 ± 4.168 (9.541)	1621.7 ± 196.040 (66.02)	3 ± 5.7 (9.4)
Lead-214, Dissolved (EPA 901.1)	-9.1 ± 8.4 (13.9)	0 ± 11.947 (22.78)	3990.1 ± 429.570 (59.09)	113.2 ± 16.304 (11.11)	3.6 ± 7.1 (11.7)
Lead-214, Total (EPA 901.1)	12.9 ± 8.6 (13.5)	0 ± 9.755 (21)	11.641 ± 9.172 (10.6)	6183.9 ± 666.770 (83.91)	-1 ± 8.4 (13.9)
Potassium-40, Dissolved (EPA 901.1)	55 ± 48 (78)	0 ± 73.330 (192.2)	0 ± 121.870 (261.7)	153.87 ± 56.967 (51.02)	-43 ± 98 (166)
Potassium-40, Total (EPA 901.1)	120 ± 140 (220)	0 ± 90.521 (192.2)	17.429 ± 44.542 (53.76)	204.12 ± 307.190 (305.2)	-96 ± 46 (78)
Radium-226, Dissolved (EPA 901.1)	17 ± 67 (110)	0 ± 110.980 (240.1)	254.23 ± 451.840 (540.6)	44.007 ± 103.980 (128.6)	10 ± 110 (180)
Radium-226, Total (EPA 901.1)	-30 ± 120 (210)	0 ± 102.250 (256.4)	0 ± 38.887 (122.7)	32.493 ± 635.900 (770)	5 ± 66 (110)
Radium-228, Dissolved (EPA 901.1)	4.8 ± 9.1 (19.5)	0.448 ± 34.301 (43.22)	47.093 ± 73.980 (76.54)	12.267 ± 9.673 (19.95)	4 ± 25 (43)
Radium-228, Total (EPA 901.1)	15 ± 19 (30)	0 ± 15.389 (54.22)	4.586 ± 15.790 (18.22)	6.953 ± 102.350 (110.6)	-3 ± 11 (19)
Thallium-208, Dissolved (EPA 901.1)	-1 ± 3.3 (5.5)	0 ± 4.219 (10.49)	0 ± 4.529 (26.23)	4.204 ± 4.813 (5.453)	4.6 ± 3.9 (6.3)
Thallium-208, Total (EPA 901.1)	-3.3 ± 7.4 (12.7)	0 ± 5.660 (12.82)	0 ± 2.277 (5.75)	0 ± 11.613 (37.38)	-0.7 ± 3.3 (5.6)
Thorium-227, Dissolved (EPA 901.1)	1 ± 15 (25)				4 ± 29 (48)
Thorium-227, Total (EPA 901.1)	-29 ± 21 (36)				-10 ± 15 (26)
Thorium-232, Dissolved (EPA 901.1)	4.8 ± 9.1 (19.5)	1621.9 ± 4696.100 (5768)	-2891.6 ± 12811.000 (15380)	-4078.5 ± 8549.500 (10290)	4 ± 25 (43)
Thorium-232, Total (EPA 901.1)	15 ± 19 (30)	-2043.6 ± 5291.000 (6465)	0 ± 4624.000 (10330)	194.63 ± 17777.000 (21420)	-3 ± 11 (19)
Thorium-234, Dissolved (EPA 901.1)	49 ± 63 (105)	10,514 ± 271.710 (344.3)	0 ± 451.110 (662.2)	0 ± 153.520 (569.2)	148 ± 92 (146)
Thorium-234, Total (EPA 901.1)	-10 ± 100 (170)	0 ± 110.800 (360.7)	161.38 ± 394.500 (501.3)	0 ± 607.490 (1214)	62 ± 64 (104)
Uranium-235 (EPA 901.1)					
Uranium-235, Dissolved (EPA 901.1)					
Uranium-238 (EPA 901.1)					
Uranium-238, Dissolved (EPA 901.1)					

Notes:

1.) Act + Unc (MDC) = Activity ± Uncertainty (Minimum Detectable Concentration)

2.) µg/L = micrograms per liter

3.) Each of EPA 901.1, EPA 903.1, EPA 904.0, EPA 908.0, ASTM D5174-97, and HASL-300 are laboratory analysis methods.

4.) Dissolved - Indicates sample filtered with 0.45 micron filter prior to analysis.

5.) pCi/L = picocuries per liter

6.) The EPA 901.1 method results are for non-quantitative purposes only due to the method's high degree of uncertainty.

Exhibit F - Hyland Facility Associates Leachate Sample Analysis 2013-2017

Parameter	PLCS 11/12/2013	PLCS 2/24/2014	PLCS 8/5/2014	PLCS 7/30/2015	PLCS 11/3/2015
Field Parameters					
Field pH (std. units)		7.46	7.59	8.34	8
ORP (mV)		79.5	49.4	125.5	14.2
Specific Conductivity (us/cm)		11850	18137	13102	14305
Temperature (deg. C)		16.5	29.92	26	17.34
Turbidity (NTU)		91.2	54.1	130	47.2
Radionuclide Act + Unc (MDC)[1] µg/L[2]					
Total Uranium, Dissolved[3] (ASTM D5174-97)[4]					
Total Uranium (ASTM D5174-97)					
Radionuclide Act + Unc (MDC) pCi/L[5]					
Radium-226 (EPA 903.1)	6.12 ± 3.54 (1.38)	4.12 ± 2.33 (2.25)	4.1 ± 1.95 (0.617)	2.8 ± 1.50 (0.542)	1.67 ± 1.19 (1.5)
Radium-226, Dissolved (EPA 903.1)	3.67 ± 1.59 (0.452)	3.24 ± 1.39 (1.25)	5.82 ± 2.29 (0.584)	2.78 ± 1.71 (1.96)	2.37 ± 1.23 (0.428)
Radium-228 (EPA 904.0)	3.47 ± 6.92 (12.8)	10.9 ± 5.50 (9.49)	3.47 ± 1.12 (1.48)	2.53 ± 0.907 (1.31)	4.77 ± 1.14 (0.885)
Radium-228, Dissolved (EPA 904.0)	3.11 ± 1.31 (2.01)	2.33 ± 1.10 (1.74)	3.55 ± 1.24 (1.71)	2.01 ± 0.662 (0.899)	2.96 ± 0.842 (0.882)
Total Uranium (EPA 908.0)	-0.0944 ± 0.820 (1.47)	1.73 ± 0.983 (1.36)	0.112 ± 0.515 (0.919)	0.0561 ± 0.328 (0.648)	0.703 ± 0.411 (0.616)
Total Uranium, Dissolved (EPA 908.0)	0.463 ± 0.762 (1.29)	2.54 ± 0.932 (0.943)	0.458 ± 0.552 (0.914)	0.551 ± 0.387 (0.625)	0.489 ± 0.429 (0.735)
Radionuclide Act + Unc (MDC) pCi/L (EPA 901.1 Results)[6]					
Actinium-228 (EPA 901.1)	5.515 ± 22.017 (42.32)	2.045 ± 8.465 (15.86)		3.993 ± 5.605 (17.08)	20.59 ± 23.511 (30.23)
Actinium-228, Dissolved (EPA 901.1)	-0.338 ± 15.114 (28.69)	-3.456 ± 596.730 (18.21)		0 ± 10.705 (48.11)	8.262 ± 21.656 (23.18)
Bismuth-212 (EPA 901.1)	-7.904 ± 316.170 (144.6)	0.7 ± 31.300 (58.37)		46.651 ± 42.470 (44.97)	± 107.34 (129.3)
Bismuth-212, Dissolved (EPA 901.1)	18.981 ± 44.302 (78.13)	-5.805 ± 232.200 (79.56)		38.373 ± 125.210 (139.5)	17.061 ± 61.957 (71)
Bismuth-214 (EPA 901.1)	43.991 ± 16.179 (17.44)	3.701 ± 6.226 (10.8)		37.473 ± 11.117 (9.653)	147.95 ± 29.708 (20.34)
Bismuth-214, Dissolved (EPA 901.1)	67.138 ± 18.503 (17.23)	3.979 ± 5.691 (9.848)		454.79 ± 59.211 (21.55)	67.392 ± 17.235 (13.06)
Cesium-134 (EPA 901.1)	0 ± 12.249 (21.1)	-0.859 ± 3.164 (5.442)		-1.651 ± 4.067 (4.465)	3.454 ± 8.043 (9.121)
Cesium-134, Dissolved (EPA 901.1)	-0.543 ± 9.699 (16.33)	-0.429 ± 2.463 (4.331)		1.802 ± 7.703 (8.464)	2.345 ± 3.696 (7.138)
Cesium-137 (EPA 901.1)	0.95 ± 4.724 (8.785)	0 ± 3.576 (6.304)		0 ± 0.556 (4.503)	0 ± 4.611 (9.658)
Cesium-137, Dissolved (EPA 901.1)	0.497 ± 3.939 (6.999)	1.36 ± 2.543 (4.318)		1.407 ± 7.014 (7.88)	4.144 ± 5.349 (5.642)
Lead-212 (EPA 901.1)	-0.005 ± 9.025 (16.76)	8.182 ± 11.019 (9.428)		12.357 ± 11.523 (8.309)	35.286 ± 16.083 (15.37)
Lead-212, Dissolved (EPA 901.1)	-2.351 ± 13.129 (14.29)	8.639 ± 9.887 (9.224)		108.2 ± 25.947 (19.77)	3.364 ± 8.324 (10.17)
Lead-214 (EPA 901.1)	60.095 ± 18.014 (19.39)	10.73 ± 14.450 (10.46)		43.048 ± 11.308 (9.196)	± 28.83 (22.09)
Lead-214, Dissolved (EPA 901.1)	56.966 ± 14.340 (15.28)	14.123 ± 16.161 (10.5)		419.77 ± 53.289 (18.76)	55.287 ± 13.132 (10.79)
Potassium-40 (EPA 901.1)	190.97 ± 101.430 (154.2)	372.63 ± 68.344 (41.62)		462.51 ± 78.200 (43.9)	419.75 ± 134.780 (126.6)
Potassium-40, Dissolved (EPA 901.1)	342 ± 81.582 (88.58)	402.6 ± 78.197 (49.2)		456.59 ± 112.540 (92.55)	431.27 ± 77.856 (28.92)
Radium-226 (EPA 901.1)	24.563 ± 103.870 (196.6)	120.17 ± 99.079 (115.3)		0 ± 65.125 (116.1)	144.56 ± 177.340 (213.3)
Radium-226, Dissolved (EPA 901.1)	-50.575 ± 148.230 (171.2)	-7.471 ± 67.488 (94.55)		9.698 ± 191.860 (240)	25.579 ± 100.980 (127.9)
Radium-228 (EPA 901.1)	5.515 ± 22.017 (42.32)	2.045 ± 8.465 (15.86)		3.993 ± 5.605 (17.08)	20.59 ± 23.511 (30.23)
Radium-228, Dissolved (EPA 901.1)	-0.338 ± 15.114 (28.69)	-3.456 ± 596.730 (18.21)		0 ± 10.705 (48.11)	8.262 ± 21.656 (23.18)
Thallium-208 (EPA 901.1)	-0.861 ± 8.845 (10.59)	-1.618 ± 64.703 (5.703)		0 ± 2.212 (4.705)	0.93 ± 7.435 (9.519)
Thallium-208, Dissolved (EPA 901.1)	-0.88 ± 5.732 (7.937)	-0.915 ± 9.408 (5.161)		1.652 ± 9.519 (10.64)	1.73 ± 4.735 (5.515)
Thorium-232 (EPA 901.1)	191.31 ± 3048.900 (5441)	-1113.8 ± 65920.000 (10390)		2123.2 ± 6417.000 (7842)	908.25 ± 4575.300 (5661)
Thorium-232, Dissolved (EPA 901.1)	-911.44 ± 3403.100 (3149)	1054.6 ± 6015.000 (10360)		2800.4 ± 5121.400 (6175)	0 ± 5271.800 (10580)
Thorium-234 (EPA 901.1)	-16.829 ± 229.480 (313.4)	15.669 ± 299.010 (524.1)		42.353 ± 56.431 (464.4)	0 ± 140.500 (353.9)
Thorium-234, Dissolved (EPA 901.1)	-78.906 ± 331.990 (248.6)	-81.945 ± 25269.000 (562.6)		0 ± 143.330 (369.7)	± 437.04 (555.5)

Notes:

1.) Act + Unc (MDC) = Activity ± Uncertainty (Minimum Detectable Concentration)

2.) µg/L = micrograms per liter

3.) Dissolved - Indicates sample filtered with 0.45 micron filter prior to analysis.

4.) Each of EPA 901.1, EPA 903.1, EPA 904.0, EPA 908.0, and ASTM D5174-97 are laboratory analysis methods.

5.) pCi/L = picocuries per liter

6.) The EPA 901.1 method results are for non-quantitative purposes only due to the method's high degree of uncertainty.

7.) 8/16/2017 sample results for Bismuth-214, Cesium-137 and Lead-214 are anomalously elevated and a resample was collected on 12/26/2017.

Exhibit F - Hyland Facility Associates Leachate Sample Analysis 2013-2017

Parameter	PLCS 2/1/2016	PLCS 8/10/2016	PLCS 2/7/2017	PLCS 8/16/2017	PLCS Resample 12/26/2017
Field Parameters					
Field pH (std. units)	8.01	8.19	8.08	8.1	7.01
ORP (mV)	25.6	15.8	39.4	-36.6	72.6
Specific Conductivity (us/cm)	17526	21439	16413	19593	18954
Temperature (deg. C)	7.8	22.5	6.4	28.3	2.8
Turbidity (NTU)	55.6	52.8	49.6	51.3	64.2
Radionuclide Act + Unc (MDC)[1] µg/L[2]					
Total Uranium, Dissolved[3] (ASTM D5174-97)[4]		0.000566 ± 0.037 (1.927)	0.000119 ± 0.007 (0.385)	0.000575 ± 0.032 (0.385)	
Total Uranium (ASTM D5174-97)		0.000563 ± 0.038 (1.927)	0.000099 ± 0.008 (0.385)	0.000654 ± 0.036 (0.385)	
Radionuclide Act + Unc (MDC) pCi/L[5]					
Radium-226 (EPA 903.1)	4.62 ± 1.89 (1.93)	4.24 ± 1.50 (1.16)	2.38 ± 1.52 (1.83)	13.4 ± 8.07 (3.3)	
Radium-226, Dissolved (EPA 903.1)	4.36 ± 2.08 (0.657)	4.92 ± 1.58 (0.952)	2.65 ± 1.74 (2.33)	9.76 ± 4.42 (1.32)	
Radium-228 (EPA 904.0)	5.7 ± 1.42 (1.17)	11.6 ± 3.12 (3.36)	10.3 ± 2.24 (1.54)	4.46 ± 1.49 (1.94)	
Radium-228, Dissolved (EPA 904.0)	3.91 ± 0.954 (0.888)	8.75 ± 4.95 (8.8)	4.98 ± 1.31 (1.5)	6.84 ± 1.82 (1.69)	
Total Uranium (EPA 908.0)	0.516 ± 0.406 (0.681)				
Total Uranium, Dissolved (EPA 908.0)	0.35 ± 0.365 (0.644)				
Radionuclide Act + Unc (MDC) pCi/L (EPA 901.1 Results)[6]					
Actinium-228 (EPA 901.1)	0 ± 12.207 (39.68)	9.319 ± 13.696 (14.78)	5.923 ± 9.060 (22.45)	0 ± 39.124 (51.53)	
Actinium-228, Dissolved (EPA 901.1)	13.661 ± 28.445 (30.72)	0 ± 13.906 (38.66)	44.748 ± 21.746 (20.16)	7.712 ± 82.070 (82.86)	
Bismuth-212 (EPA 901.1)	19.159 ± 80.934 (97.51)	27.836 ± 46.506 (49.79)	29.621 ± 49.575 (62.66)	0 ± 88.422 (169.1)	
Bismuth-212, Dissolved (EPA 901.1)	37.735 ± 87.708 (98.71)	18.905 ± 93.113 (106.5)	16.223 ± 74.421 (81.05)	0 ± 136.280 (288.4)	
Bismuth-214 (EPA 901.1)	47.939 ± 21.084 (21.88)	16.226 ± 13.359 (10.23)	24.85 ± 8.717 (6.939)	8936.4 ± 946.510 (31.55)[7]	29 ± 12 (17)
Bismuth-214, Dissolved (EPA 901.1)	24.135 ± 15.909 (17.65)	0 ± 10.215 (23.91)	276.89 ± 36.510 (12.58)	13163 ± 1384.200 (48.85)[7]	3 ± 13 (21)
Cesium-134 (EPA 901.1)	2.345 ± 9.211 (10.44)	0 ± 1.775 (4.986)	0.457 ± 4.127 (4.701)	0 ± 7.079 (13.89)	
Cesium-134, Dissolved (EPA 901.1)	0 ± 2.329 (7.988)	1.203 ± 7.255 (8.255)	0 ± 1.032 (8.387)	3.065 ± 22.692 (22.41)	
Cesium-137 (EPA 901.1)	-1.29 ± 7.973 (9.412)	1.069 ± 3.886 (4.042)	2.383 ± 3.597 (3.768)	13.499 ± 13.009 (12.12)[7]	0.5 ± 4.9 (8.3)
Cesium-137, Dissolved (EPA 901.1)	0.039 ± 7.270 (8.336)	1.96 ± 6.178 (6.82)	0.098 ± 5.954 (6.449)	21.627 ± 19.055 (18.55)[7]	-0.6 ± 3.1 (5.5)
Lead-212 (EPA 901.1)	0 ± 7.531 (19.73)	5.678 ± 5.590 (6.872)	0 ± 3.543 (9.704)	34.983 ± 19.096 (29.07)	
Lead-212, Dissolved (EPA 901.1)	0 ± 8.012 (15.24)	0 ± 7.464 (14.92)	84.215 ± 39.352 (13.15)	3415.5 ± 365.240 (45.2)	
Lead-214 (EPA 901.1)	39.67 ± 16.682 (17.42)	5.231 ± 7.404 (8.555)	2.008 ± 10.232 (11.68)	9398.7 ± 1002.000 (39.84)[7]	13.3 ± 9.3 (14.7)
Lead-214, Dissolved (EPA 901.1)	29.84 ± 14.679 (15.02)	2.969 ± 12.481 (15.97)	280.19 ± 35.994 (17.14)	13736 ± 1443.500 (60.04)[7]	-5.6 ± 9.9 (16.7)
Potassium-40 (EPA 901.1)	505.44 ± 133.400 (109.1)	571.64 ± 98.917 (57.65)	330.27 ± 102.130 (83.9)	591.1 ± 178.300 (140.9)	
Potassium-40, Dissolved (EPA 901.1)	459.49 ± 112.050 (96.74)	667.21 ± 136.520 (96.85)	478.85 ± 93.506 (58.83)	501.49 ± 166.210 (212.6)	
Radium-226 (EPA 901.1)	-11.987 ± 183.420 (229.1)	30.834 ± 77.633 (99.78)	36.81 ± 102.950 (126.7)	288.9 ± 350.520 (408.3)	
Radium-226, Dissolved (EPA 901.1)	202.63 ± 117.150 (133.1)	80.803 ± 140.410 (170.7)	281.67 ± 146.250 (160.3)	0 ± 280.800 (578.1)	
Radium-228 (EPA 901.1)	0 ± 12.207 (39.68)	9.319 ± 13.696 (14.78)	5.923 ± 9.060 (22.45)	0 ± 39.124 (51.53)	
Radium-228, Dissolved (EPA 901.1)	13.661 ± 28.445 (30.72)	0 ± 13.906 (38.66)	44.748 ± 21.746 (20.16)	7.712 ± 82.070 (82.86)	
Thallium-208 (EPA 901.1)	4.241 ± 8.289 (9.449)	1.16 ± 3.737 (4.105)	0 ± 21.246 (6.239)	10.775 ± 9.788 (12.72)	
Thallium-208, Dissolved (EPA 901.1)	0 ± 2.457 (10.37)	0 ± 5.586 (11.84)	0 ± 2.714 (7.224)	12.059 ± 20.889 (21.77)	
Thorium-232 (EPA 901.1)	3341.1 ± 4418.700 (5327)	251.33 ± 6727.300 (8292)	1389.5 ± 8351.400 (10290)	0 ± 11510.000 (28450)	
Thorium-232, Dissolved (EPA 901.1)	-652.48 ± 3669.800 (4494)	1044 ± 3585.500 (4403)	1047.1 ± 9720.000 (11940)	-514.2 ± 7161.300 (10980)	
Thorium-234 (EPA 901.1)	120.21 ± 247.440 (308.7)	273.3 ± 335.340 (411.9)	98.696 ± 65.192 (566.9)	0 ± 530.520 (1565)	
Thorium-234, Dissolved (EPA 901.1)	31.547 ± 188.950 (233.8)	0 ± 116.660 (262.5)	0 ± 172.280 (679.2)	54.036 ± 764.750 (899.1)	

Notes:

1.) Act + Unc (MDC) = Activity ± Uncertainty (Minimum Detectable Concentration)

2.) µg/L = micrograms per liter

3.) Dissolved - Indicates sample filtered with 0.45 micron filter prior to analysis.

4.) Each of EPA 901.1, EPA 903.1, EPA 904.0, EPA 908.0, and ASTM D5174-97 are laboratory analysis methods.

5.) pCi/L = picocuries per liter

6.) The EPA 901.1 method results are for non-quantitative purposes only due to the method's high degree of uncertainty.

7.) 8/16/2017 sample results for Bismuth-214, Cesium-137 and Lead-214 are anomalously elevated and a resample was collected on 12/26/2017.

Exhibit F - Chemung County Landfill Leachate Sample Analysis 2012-2017

Parameter	Leachate Pond 1/31/2012	Leachate Pond 1/9/2013	Leachate Pond 1/24/2014	Leachate Pond 3/25/2015
Field Parameters				
Field pH (std. units)				7.72
ORP (mV)				51.2
Specific Conductivity (us/cm)				5288
Temperature (deg. C)				5.2
Turbidity (NTU)				98.3
Radionuclide Act + Unc (MDC)[1] µg/L[2]				
Total Uranium (ASTM D5174-97)[3]				
Total Uranium, Dissolved[4] (ASTM D5174-97)				
Radionuclide Act + Unc (MDC) pCi/L[5]				
Radium-226 (EPA 903.1)	0.74 ±0.21	3.63 ±1.4	2.87 ±2.92	2.67 ± 1.77 (0.803)
Radium-226, Dissolved (EPA 903.1)	0.39 ±0.16	1.12 ±0.83	4.41 ±3.28	1.80 ± 1.14 (1.27)
Radium-228 (EPA 904.0)	0.39 U ±0.46	1.77 ±0.852	6.26 ±2.62	1.59 ± 0.698 (1.08)
Radium-228, Dissolved (EPA 904.0)	0.77 ± 0.5	0.799 ±0.6	1.89 ±1.98	1.47 ± 0.532 (0.791)
Total Uranium (EPA 908.0)	1.34 ±3.08	1 ±0.498	0.451 ±0.215	1.76 ± 1.72 (2.9)
Total Uranium, Dissolved (EPA 908.0)	2.75 ±3.47	0.156 ±0.393	0.451 ±0.215	-0.323 ± 1.64 (3.15)
Thorium-228 (HSL-300)				
Thorium-228, Dissolved (HSL-300)				
Thorium-230 (HSL-300)				
Thorium-230, Dissolved (HSL-300)				
Thorium-232 (HSL-300)				
Thorium-232, Dissolved (HSL-300)				
Uranium-234 (HSL-300)				
Uranium-234, Dissolved (HSL-300)				
Uranium-235 (HSL-300)				
Uranium-235, Dissolved (HSL-300)				
Uranium-238 (HSL-300)				
Uranium-238, Dissolved (HSL-300)				
Radionuclide Act + Unc (MDC) pCi/L (EPA 901.1 Results)[6]				
Actinium-228 (EPA 901.1)				0.000 ± 8.005 (39.03)
Actinium-228, Dissolved (EPA 901.1)				7.288 ± 7.418 (18.72)
Bismuth-212 (EPA 901.1)				0.000 ± 16.147 (146.5)
Bismuth-212, Dissolved (EPA 901.1)				0.000 ± 27.240 (70.27)
Bismuth-214 (EPA 901.1)				8.033 ± 16.322 (19.96)
Bismuth-214, Dissolved (EPA 901.1)				16.623 ± 8.031 (6.716)
Cesium-134 (EPA 901.1)				1.376 ± 6.326 (7.193)
Cesium-134, Dissolved (EPA 901.1)				1.308 ± 1.516 (4.941)
Cesium-137 (EPA 901.1)	1 U ±60	0.749 ±3.123	0.0511 ±2.592	-2.376 ± 9.488 (10.94)
Cesium-137, Dissolved (EPA 901.1)	-1.6 U ±7.0	-0.631 ±3.5	-0.123 ±2.369	-0.203 ± 4.011 (4.508)
Lead-212 (EPA 901.1)				0.000 ± 7.651 (16.14)
Lead-212, Dissolved (EPA 901.1)				14.777 ± 12.861 (10.27)
Lead-214 (EPA 901.1)				0.000 ± 10.970 (22.08)
Lead-214, Dissolved (EPA 901.1)				16.166 ± 8.824 (10.9)
Potassium-40 (EPA 901.1)				66.721 ± 101.690 (139.6)
Potassium-40, Dissolved (EPA 901.1)				80.958 ± 85.070 (83.35)
Radium-226 (EPA 901.1)				0.000 ± 98.681 (196.8)
Radium-226, Dissolved (EPA 901.1)				3.974 ± 94.014 (120.1)
Radium-228 (EPA 901.1)				0.000 ± 8.005 (39.03)
Radium-228, Dissolved (EPA 901.1)				7.288 ± 7.418 (18.72)
Thallium-208 (EPA 901.1)				6.021 ± 6.336 (7.219)
Thallium-208, Dissolved (EPA 901.1)				0.667 ± 4.388 (5.25)
Thorium-232 (EPA 901.1)				3227.500 ± 4073.400 (4907)
Thorium-232, Dissolved (EPA 901.1)				3723.200 ± 6725.500 (8203)
Thorium-234 (EPA 901.1)				69.068 ± 235.340 (300)
Thorium-234, Dissolved (EPA 901.1)				0.000 ± 130.700 (541.6)
Uranium-235 (EPA 901.1)		-3.295 ±6.267	3.564 ±21.715	0.000 ± 28.299 (61.65)
Uranium-235, Dissolved (EPA 901.1)		2.184 ±4.167	-3.144 ±247.07	32.649 ± 25.419 (31.36)
Uranium-238 (EPA 901.1)				84.035 ± 117.530 (146.4)
Uranium-238, Dissolved (EPA 901.1)				0.000 ± 62.721 (138.1)

Notes:

1.) Act + Unc (MDC) = Activity ± Uncertainty (Minimum Detectable Concentration)

2.) µg/L = micrograms per liter

3.) Each of EPA 901.1, HSL-300, EPA 903.1, EPA 904.0, ASTM D5174-97, and EPA 908.0 are laboratory analysis methods

4.) Dissolved - Indicates sample filtered with 0.45 micron filter prior to analysis.

5.) pCi/L = picocuries per liter

6.) The EPA 901.1 method results are for non-quantitative purposes only due to the method's high degree of uncertainty.

Exhibit F - Chemung County Landfill Leachate Sample Analysis 2012-2017

Parameter	Leachate Pond 1/12/2016	Leachate Pond 1/11/2017	Cells 1-3 Primary Leachate 5/13/2010	Cells 1-3 Primary Leachate 1/31/2012
Field Parameters				
Field pH (std. units)	8.06	7.85		
ORP (mV)	54.4	100.4		
Specific Conductivity (us/cm)	9260	6135		
Temperature (deg. C)	5.2	5.66		
Turbidity (NTU)	36.3	23.3		
Radionuclide Act + Unc (MDC)[1] µg/L[2]				
Total Uranium (ASTM D5174-97)[3]		0.000213 ± 0.004 (0.385)		
Total Uranium, Dissolved[4] (ASTM D5174-97)		0.000349 ± 0.007 (0.385)		
Radionuclide Act + Unc (MDC) pCi/L[5]				
Radium-226 (EPA 903.1)	1.47 ± 1.04 (0.5)	1.23 ± 0.974 (1.32)	3.3 ±1.8	1.72 ±0.55
Radium-226, Dissolved (EPA 903.1)	2.04 ± 1.28 (0.552)	1.02 ± 0.565 (0.503)		1.59 ±0.46
Radium-228 (EPA 904.0)	1.6 ± 0.644 (0.99)	1.57 ± 1.02 (1.92)	12.3 ±7.2	1.4 ±1.3
Radium-228, Dissolved (EPA 904.0)	1.28 ± 0.662 (1.17)	0.432 ± 0.518 (1.09)		1.76 ±0.99
Total Uranium (EPA 908.0)	0.865 ± 0.416 (0.58)			-1.34 ±3.73
Total Uranium, Dissolved (EPA 908.0)	0.524 ± 0.367 (0.603)			3.65 3.52
Thorium-228 (HSL-300)			0.18 U ±0.41	
Thorium-228, Dissolved (HSL-300)				
Thorium-230 (HSL-300)			0.68 U ±0.7	
Thorium-230, Dissolved (HSL-300)				
Thorium-232 (HSL-300)			0 U ±0.12	
Thorium-232, Dissolved (HSL-300)				
Uranium-234 (HSL-300)			1.6 U ±1.3	
Uranium-234, Dissolved (HSL-300)				
Uranium-235 (HSL-300)			-0.22 U ±0.22	
Uranium-235, Dissolved (HSL-300)				
Uranium-238 (HSL-300)			0.33 U ±0.67	
Uranium-238, Dissolved (HSL-300)				
Radionuclide Act + Unc (MDC) pCi/L (EPA 901.1 Results)[6]				
Actinium-228 (EPA 901.1)	0 ± 2.338 (19.86)	0.000 ± 19.832 (47.1)		
Actinium-228, Dissolved (EPA 901.1)	19.544 ± 16.100 (17.82)	7.329 ± 17.168 (18.07)		
Bismuth-212 (EPA 901.1)	0 ± 33.291 (81.02)	-35.196 ± 142.410 (150.6)		
Bismuth-212, Dissolved (EPA 901.1)	0 ± 58.677 (188)	16.137 ± 65.062 (70.47)		
Bismuth-214 (EPA 901.1)	47.393 ± 14.893 (11.6)	95.057 ± 23.152 (17.7)		
Bismuth-214, Dissolved (EPA 901.1)	0.642 ± 17.903 (23.24)	161.35 ± 24.393 (12.78)		
Cesium-134 (EPA 901.1)	4.527 ± 5.523 (5.718)	0.000 ± 2.772 (8.419)		
Cesium-134, Dissolved (EPA 901.1)	1.7 ± 7.333 (8.522)	0.000 ± 1.605 (5.754)		
Cesium-137 (EPA 901.1)	0 ± 1.827 (5.652)	0.000 ± 4.598 (10.28)		20 U ±4.9
Cesium-137, Dissolved (EPA 901.1)	-2.038 ± 8.788 (10.21)	0.000 ± 1.962 (6.327)		20 U ±2.4
Lead-212 (EPA 901.1)	13.975 ± 17.265 (9.783)	27.294 ± 21.496 (17.85)		
Lead-212, Dissolved (EPA 901.1)	0 ± 10.061 (18.4)	35.583 ± 31.545 (11.99)		
Lead-214 (EPA 901.1)	41.483 ± 11.210 (9.96)	90.508 ± 20.736 (16.48)		
Lead-214, Dissolved (EPA 901.1)	4.355 ± 13.613 (18.06)	174.73 ± 24.750 (11.8)		
Potassium-40 (EPA 901.1)	279.14 ± 72.088 (55.12)	139.45 ± 91.152 (83.74)		
Potassium-40, Dissolved (EPA 901.1)	213.02 ± 106.560 (125.1)	207.09 ± 59.111 (47.94)		
Radium-226 (EPA 901.1)	0 ± 66.834 (133.5)	0.000 ± 103.770 (197.7)		
Radium-226, Dissolved (EPA 901.1)	60.685 ± 171.350 (209.3)	0.000 ± 87.971 (165)		
Radium-228 (EPA 901.1)	0 ± 2.338 (19.86)	0.000 ± 19.832 (47.1)		
Radium-228, Dissolved (EPA 901.1)	19.544 ± 16.100 (17.82)	7.329 ± 17.168 (18.07)		
Thallium-208 (EPA 901.1)	2.835 ± 4.076 (5.972)	3.551 ± 5.730 (9.951)		
Thallium-208, Dissolved (EPA 901.1)	0 ± 2.426 (11.08)	1.614 ± 4.944 (5.683)		
Thorium-232 (EPA 901.1)	934.04 ± 8484.300 (10390)	1472.1 ± 10570.000 (12980)		
Thorium-232, Dissolved (EPA 901.1)	0 ± 2873.700 (6141)	0.000 ± 4864.800 (11080)		
Thorium-234 (EPA 901.1)	141.15 ± 435.470 (546.8)	244.04 ± 556.100 (692.9)		
Thorium-234, Dissolved (EPA 901.1)	21.174 ± 254.960 (322.8)	0.000 ± 280.190 (602.5)		
Uranium-235 (EPA 901.1)				
Uranium-235, Dissolved (EPA 901.1)				
Uranium-238 (EPA 901.1)				
Uranium-238, Dissolved (EPA 901.1)				

Notes:

1.) Act + Unc (MDC) = Activity ± Uncertainty (Minimum Detectable Concentration)

2.) µg/L = micrograms per liter

3.) Each of EPA 901.1, HSL-300, EPA 903.1, EPA 904.0, ASTM D5174-97, and EPA 908.0 are laboratory analysis methods

4.) Dissolved - Indicates sample filtered with 0.45 micron filter prior to analysis.

5.) pCi/L = picocuries per liter

6.) The EPA 901.1 method results are for non-quantitative purposes only due to the method's high degree of uncertainty.

Exhibit F - Chemung County Landfill Leachate Sample Analysis 2012-2017

Parameter	Cells 1-3 Primary Leachate 1/9/2013	Cells 1-3 Primary Leachate 1/24/2014	Cells 1-3 Primary Leachate 3/25/2015	Cells 1-3 Primary Leachate 1/12/2016
Field Parameters				
Field pH (std. units)			8.33	7.72
ORP (mV)			203	51.6
Specific Conductivity (us/cm)			10689	13641
Temperature (deg. C)			9.6	11.4
Turbidity (NTU)			14.7	29.9
Radionuclide Act + Unc (MDC)[1] µg/L[2]				
Total Uranium (ASTM D5174-97)[3]				
Total Uranium, Dissolved[4] (ASTM D5174-97)				
Radionuclide Act + Unc (MDC) pCi/L[5]				
Radium-226 (EPA 903.1)	7 ±2.01	4.18 ±3.02	6.49 ± 3.75 (1.47)	1.7 ± 1.00 (0.987)
Radium-226, Dissolved (EPA 903.1)	1.91 ± 0.975	4.45 ± 6.03	1.98 ± 1.12 (1.19)	3.49 ± 1.35 (0.983)
Radium-228 (EPA 904.0)	-0.388 ±2.16	1.11 ±1.73	-0.531 ± 2.09 (4.04)	3.31 ± 0.951 (1.08)
Radium-228, Dissolved (EPA 904.0)	1.43 ±0.652	0.466 ±1.85	2.00 ± 0.689 (0.951)	2.09 ± 0.731 (1.06)
Total Uranium (EPA 908.0)	0.742 ±0.449	1.12 ±0.855	0.511 ± 1.95 (3.6)	0.252 ± 0.340 (0.619)
Total Uranium, Dissolved (EPA 908.0)	0.383 ±0.602	1.52 ±1.28	1.95 ± 2.14 (3.69)	0.875 ± 0.435 (0.618)
Thorium-228 (HSL-300)				
Thorium-228, Dissolved (HSL-300)				
Thorium-230 (HSL-300)				
Thorium-230, Dissolved (HSL-300)				
Thorium-232 (HSL-300)				
Thorium-232, Dissolved (HSL-300)				
Uranium-234 (HSL-300)				
Uranium-234, Dissolved (HSL-300)				
Uranium-235 (HSL-300)				
Uranium-235, Dissolved (HSL-300)				
Uranium-238 (HSL-300)				
Uranium-238, Dissolved (HSL-300)				
Radionuclide Act + Unc (MDC) pCi/L (EPA 901.1 Results)[6]				
Actinium-228 (EPA 901.1)			0.000 ± 2.858 (18.72)	13.343 ± 14.766 (16.63)
Actinium-228, Dissolved (EPA 901.1)			0.000 ± 15.328 (45.43)	0 ± 11.461 (22.61)
Bismuth-212 (EPA 901.1)			55.140 ± 70.764 (56.4)	0 ± 13.360 (80.96)
Bismuth-212, Dissolved (EPA 901.1)			28.964 ± 80.088 (94.96)	4.413 ± 65.264 (72.62)
Bismuth-214 (EPA 901.1)			19.175 ± 7.940 (7.01)	59.412 ± 14.384 (10.15)
Bismuth-214, Dissolved (EPA 901.1)			22.926 ± 12.942 (21.15)	28.388 ± 11.819 (10.41)
Cesium-134 (EPA 901.1)			1.853 ± 3.313 (3.536)	0 ± 1.092 (5.027)
Cesium-134, Dissolved (EPA 901.1)			0.195 ± 7.985 (9.154)	0 ± 0.966 (5.04)
Cesium-137 (EPA 901.1)	-3.193 ±6.036	0.385 ±2.642	0.178 ± 4.696 (5.215)	0 ± 1.362 (6.221)
Cesium-137, Dissolved (EPA 901.1)	0.781 ±2.647	-0.812 ±3.054	1.562 ± 8.004 (9.415)	1.571 ± 4.115 (4.532)
Lead-212 (EPA 901.1)			0.000 ± 4.616 (9.876)	10.745 ± 16.834 (10.17)
Lead-212, Dissolved (EPA 901.1)			3.092 ± 12.656 (16.14)	6.077 ± 7.249 (8.647)
Lead-214 (EPA 901.1)			16.494 ± 7.556 (8.289)	55.331 ± 12.737 (10.55)
Lead-214, Dissolved (EPA 901.1)			11.024 ± 10.927 (14.04)	30.938 ± 11.916 (10.99)
Potassium-40 (EPA 901.1)			342.650 ± 67.324 (42.17)	458.98 ± 94.254 (53.47)
Potassium-40, Dissolved (EPA 901.1)			287.360 ± 127.250 (139.6)	503.46 ± 88.841 (43.09)
Radium-226 (EPA 901.1)			0.000 ± 58.565 (114)	58.066 ± 92.353 (116.2)
Radium-226, Dissolved (EPA 901.1)			25.329 ± 151.590 (202.6)	0 ± 74.187 (143.8)
Radium-228 (EPA 901.1)			0.000 ± 2.858 (18.72)	13.343 ± 14.766 (16.63)
Radium-228, Dissolved (EPA 901.1)			0.000 ± 15.328 (45.43)	0 ± 11.461 (22.61)
Thallium-208 (EPA 901.1)			4.400 ± 4.752 (4.462)	3.599 ± 4.148 (5.806)
Thallium-208, Dissolved (EPA 901.1)			0.060 ± 7.221 (8.931)	0 ± 0.926 (6.141)
Thorium-232 (EPA 901.1)			1510.600 ± 6610.600 (8203)	1302.8 ± 7834.200 (9590)
Thorium-232, Dissolved (EPA 901.1)			875.820 ± 3893.600 (4844)	2198.4 ± 7300.400 (8893)
Thorium-234 (EPA 901.1)			0.000 ± 205.970 (487.7)	0 ± 209.850 (582.3)
Thorium-234, Dissolved (EPA 901.1)			0.000 ± 119.180 (306.4)	0 ± 133.780 (578)
Uranium-235 (EPA 901.1)	-1.049 ±23.2	33.557 ±21.17	3.597 ± 30.449 (37.36)	
Uranium-235, Dissolved (EPA 901.1)	-0.303 ±24.36	6.549 ±21.08	0.000 ± 32.346 (67.35)	
Uranium-238 (EPA 901.1)			42.150 ± 98.110 (121.4)	
Uranium-238, Dissolved (EPA 901.1)			97.251 ± 113.450 (140.6)	

Notes:

1.) Act + Unc (MDC) = Activity ± Uncertainty (Minimum Detectable Concentration)

2.) µg/L = micrograms per liter

3.) Each of EPA 901.1, HSL-300, EPA 903.1, EPA 904.0, ASTM D5174-97, and EPA 908.0 are laboratory analysis methods

4.) Dissolved - Indicates sample filtered with 0.45 micron filter prior to analysis.

5.) pCi/L = picocuries per liter

6.) The EPA 901.1 method results are for non-quantitative purposes only due to the method's high degree of uncertainty.

Exhibit F - Chemung County Landfill Leachate Sample Analysis 2012-2017

Parameter	Cells 1-3 Primary Leachate 1/11/2017	Cell 4 Primary Leachate 5/13/2010	Cell 4 Primary Leachate 1/31/2012	Cell 4 Primary Leachate 6/29/2012
Field Parameters				
Field pH (std. units)	7.69			
ORP (mV)	67.8			
Specific Conductivity (us/cm)	18010			
Temperature (deg. C)	14.5			
Turbidity (NTU)	10.1			
Radionuclide Act + Unc (MDC)[1] µg/L[2]				
Total Uranium (ASTM D5174-97)[3]	0.000157 ± 0.003 (0.385)			
Total Uranium, Dissolved[4] (ASTM D5174-97)	0.000164 ± 0.003 (0.385)			
Radionuclide Act + Unc (MDC) pCi/L[5]				
Radium-226 (EPA 903.1)	3.37 ± 1.71 (1.65)	0.7 J ±0.22	2.43 ±0.68	1.04 ±0.71
Radium-226, Dissolved (EPA 903.1)	2.71 ± 1.07 (0.911)		1.8 ±0.48	0.811 ±0.654
Radium-228 (EPA 904.0)	7.6 ± 2.49 (3.41)	0.74 J ±0.42	1.8 U ±1.5	7.01 ±4.92
Radium-228, Dissolved (EPA 904.0)	6.49 ± 3.44 (6.23)		1.91 ±0.94	4.91 ±3.02
Total Uranium (EPA 908.0)			1.65 ±3.03	0.403 ±2.75
Total Uranium, Dissolved (EPA 908.0)			-1.44 ±3.43	3.88 ±3.09
Thorium-228 (HSL-300)		-0.008 U ±0.012		1.012 ±1.02
Thorium-228, Dissolved (HSL-300)				2.88 ±2.08
Thorium-230 (HSL-300)		0.081 J 0.085		1.093 ±0.669
Thorium-230, Dissolved (HSL-300)				0.605 ±0.923
Thorium-232 (HSL-300)		0 U ±0.019		-0.199 ±0.455
Thorium-232, Dissolved (HSL-300)				0.242 ±0.672
Uranium-234 (HSL-300)		0.73 J ±0.28		15.7 ±281
Uranium-234, Dissolved (HSL-300)				2.25 ±1.76
Uranium-235 (HSL-300)		0.042 U ±0.085		0.093 ±0.424
Uranium-235, Dissolved (HSL-300)				0.49 ±1.12
Uranium-238 (HSL-300)		0.46 J ±0.22		0 ±0.325
Uranium-238, Dissolved (HSL-300)				0.536 ±0.661
Radionuclide Act + Unc (MDC) pCi/L (EPA 901.1 Results)[6]				
Actinium-228 (EPA 901.1)	0.000 ± 22.207 (51.27)			
Actinium-228, Dissolved (EPA 901.1)	10.18 ± 27.577 (27.68)			
Bismuth-212 (EPA 901.1)	75.318 ± 111.410 (122.2)			
Bismuth-212, Dissolved (EPA 901.1)	28.289 ± 82.623 (87.7)			
Bismuth-214 (EPA 901.1)	181.15 ± 33.129 (19.26)			
Bismuth-214, Dissolved (EPA 901.1)	903.39 ± 100.400 (14.67)			
Cesium-134 (EPA 901.1)	0.000 ± 3.184 (11.33)			
Cesium-134, Dissolved (EPA 901.1)	0.000 ± 1.344 (9.66)			
Cesium-137 (EPA 901.1)	0.000 ± 1.153 (10.3)		1.1 U ±7.2	-0.435 ±3.35
Cesium-137, Dissolved (EPA 901.1)	0.000 ± 3.015 (8.107)		2.6 U ±8.0	0.085 ±2.52
Lead-212 (EPA 901.1)	35.567 ± 16.631 (22.38)			
Lead-212, Dissolved (EPA 901.1)	210.73 ± 44.821 (17.14)			
Lead-214 (EPA 901.1)	201.72 ± 35.310 (21.74)			
Lead-214, Dissolved (EPA 901.1)	939.84 ± 104.490 (18.04)			
Potassium-40 (EPA 901.1)	681.73 ± 156.460 (112.2)			
Potassium-40, Dissolved (EPA 901.1)	714.7 ± 130.360 (75.97)			
Radium-226 (EPA 901.1)	7.32 ± 192.700 (249.1)			
Radium-226, Dissolved (EPA 901.1)	70.104 ± 171.590 (208.2)			
Radium-228 (EPA 901.1)	0.000 ± 22.207 (51.27)			
Radium-228, Dissolved (EPA 901.1)	10.18 ± 27.577 (27.68)			
Thallium-208 (EPA 901.1)	0.000 ± 5.192 (14.18)			
Thallium-208, Dissolved (EPA 901.1)	0.000 ± 5.903 (8.908)			
Thorium-232 (EPA 901.1)	1751.6 ± 5279.100 (6465)			
Thorium-232, Dissolved (EPA 901.1)	0.000 ± 6046.900 (15080)			
Thorium-234 (EPA 901.1)	30.408 ± 295.820 (370.4)			
Thorium-234, Dissolved (EPA 901.1)	0.000 ± 225.390 (838.3)			
Uranium-235 (EPA 901.1)				-1.2 ±47
Uranium-235, Dissolved (EPA 901.1)				-4.53 ±154
Uranium-238 (EPA 901.1)				
Uranium-238, Dissolved (EPA 901.1)				

Notes:

1.) Act + Unc (MDC) = Activity ± Uncertainty (Minimum Detectable Concentration)

2.) µg/L = micrograms per liter

3.) Each of EPA 901.1, HSL-300, EPA 903.1, EPA 904.0, ASTM D5174-97, and EPA 908.0 are laboratory analysis methods

4.) Dissolved - Indicates sample filtered with 0.45 micron filter prior to analysis.

5.) pCi/L = picocuries per liter

6.) The EPA 901.1 method results are for non-quantitative purposes only due to the method's high degree of uncertainty.

Exhibit F - Chemung County Landfill Leachate Sample Analysis 2012-2017

Parameter	Cell 4 Primary Leachate 1/9/2013	Cell 4 Primary Leachate 6/11/2013	Cell 4 Primary Leachate 1/24/2014	Cell 4 Primary Leachate 7/7/2014
Field Parameters				
Field pH (std. units)				7.4
ORP (mV)				-140.2
Specific Conductivity (us/cm)				22600
Temperature (deg. C)				25.2
Turbidity (NTU)				217
Radionuclide Act + Unc (MDC)[1] µg/L[2]				
Total Uranium (ASTM D5174-97)[3]				
Total Uranium, Dissolved[4] (ASTM D5174-97)				
Radionuclide Act + Unc (MDC) pCi/L[5]				
Radium-226 (EPA 903.1)	2.51 ± 1.96	9.43 ±4.18	9.43 ±4.18	1.69 ± 1.56 (1.96)
Radium-226, Dissolved (EPA 903.1)	0.887 ±0.794	3.7 ±3.48	4.44 ±2.92	5.18 ± 1.55 (0.998)
Radium-228 (EPA 904.0)	4.43 ±2.24	4.75 ±5.58	4.75 ±5.58	3.12 ± 2.75 (4.87)
Radium-228, Dissolved (EPA 904.0)	0.387 ±0.342	-6.51 ±7.3	4.35 ±1.88	3.76 ± 0.969 (1.02)
Total Uranium (EPA 908.0)	0.0226 ±0.363	0.11 ±0.516	0.11 ±0.516	0.423 ± 0.409 (0.661)
Total Uranium, Dissolved (EPA 908.0)	0.376 ±0.342	-0.554 ±0.626	0.805 ±0.746	0.376 ± 0.575 (0.968)
Thorium-228 (HSL-300)				
Thorium-228, Dissolved (HSL-300)				
Thorium-230 (HSL-300)				
Thorium-230, Dissolved (HSL-300)				
Thorium-232 (HSL-300)				
Thorium-232, Dissolved (HSL-300)				
Uranium-234 (HSL-300)				
Uranium-234, Dissolved (HSL-300)				
Uranium-235 (HSL-300)				
Uranium-235, Dissolved (HSL-300)				
Uranium-238 (HSL-300)				
Uranium-238, Dissolved (HSL-300)				
Radionuclide Act + Unc (MDC) pCi/L (EPA 901.1 Results)[6]				
Actinium-228 (EPA 901.1)				2.245 ± 19.123 (37.03)
Actinium-228, Dissolved (EPA 901.1)				13.887 ± 8.056 (14.08)
Bismuth-212 (EPA 901.1)				21.124 ± 70.608 (127.8)
Bismuth-212, Dissolved (EPA 901.1)				15.074 ± 35.537 (59.5)
Bismuth-214 (EPA 901.1)				82.007 ± 21.231 (17.39)
Bismuth-214, Dissolved (EPA 901.1)				20.635 ± 11.650 (9.295)
Cesium-134 (EPA 901.1)				-10.612 ± 9.641 (15.41)
Cesium-134, Dissolved (EPA 901.1)				-2.986 ± 3.088 (5.035)
Cesium-137 (EPA 901.1)	0.973 ±2.803	-0.22 ±6.717	-0.22 ±6.717	1.372 ± 5.295 (9.468)
Cesium-137, Dissolved (EPA 901.1)	-0.097 ±3.114	-0.013 ±84.85	-0.679 ±3.084	0.097 ± 2.216 (3.777)
Lead-212 (EPA 901.1)				-6.93 ± 3869.100 (19.51)
Lead-212, Dissolved (EPA 901.1)				-2.269 ± 7.822 (7.457)
Lead-214 (EPA 901.1)				81.909 ± 18.933 (20.64)
Lead-214, Dissolved (EPA 901.1)				3.055 ± 5.825 (9.994)
Potassium-40 (EPA 901.1)				626.23 ± 142.520 (115.1)
Potassium-40, Dissolved (EPA 901.1)				536.74 ± 84.699 (55.58)
Radium-226 (EPA 901.1)				92.06 ± 128.410 (187)
Radium-226, Dissolved (EPA 901.1)				39.478 ± 81.427 (106.4)
Radium-228 (EPA 901.1)				2.245 ± 19.123 (37.03)
Radium-228, Dissolved (EPA 901.1)				13.887 ± 8.056 (14.08)
Thallium-208 (EPA 901.1)				-0.763 ± 10.853 (12.18)
Thallium-208, Dissolved (EPA 901.1)				5.27 ± 3.556 (4.556)
Thorium-232 (EPA 901.1)				1375.6 ± 3044.700 (5310)
Thorium-232, Dissolved (EPA 901.1)				-1945.4 ± 274500.000 (8258)
Thorium-234 (EPA 901.1)				55.707 ± 177.240 (311.2)
Thorium-234, Dissolved (EPA 901.1)				89.068 ± 94.521 (396.2)
Uranium-235 (EPA 901.1)	2.521 ±4.534	-7.697 ±1508	-7.697 ±1508	2.216 ± 32.114 (56.78)
Uranium-235, Dissolved (EPA 901.1)	-0.106 ±9.929	-19.799 ±123.2	5.806 ±24.41	-27.905 ± 275.010 (37.84)
Uranium-238 (EPA 901.1)				-17.364 ± 129.130 (181.5)
Uranium-238, Dissolved (EPA 901.1)				120.6 ± 70.052 (486.9)

Notes:

1.) Act + Unc (MDC) = Activity ± Uncertainty (Minimum Detectable Concentration)

2.) µg/L = micrograms per liter

3.) Each of EPA 901.1, HSL-300, EPA 903.1, EPA 904.0, ASTM D5174-97, and EPA 908.0 are laboratory analysis methods

4.) Dissolved - Indicates sample filtered with 0.45 micron filter prior to analysis.

5.) pCi/L = picocuries per liter

6.) The EPA 901.1 method results are for non-quantitative purposes only due to the method's high degree of uncertainty.

Exhibit F - Chemung County Landfill Leachate Sample Analysis 2012-2017

Parameter	Cell 4 Primary Leachate 3/25/2015	Cell 4 Primary Leachate 7/7/2015	Cell 4 Primary Leachate 1/11/2016	Cell 4 Primary Leachate 7/12/2016
Field Parameters				
Field pH (std. units)	7.65	7.68	7.66	7.62
ORP (mV)	90.4	46	59.8	33.2
Specific Conductivity (us/cm)	24618	9152	12529	17651
Temperature (deg. C)	12.8	24.7	20.8	23.2
Turbidity (NTU)	54.1	291	> 1000	24.1
Radionuclide Act + Unc (MDC)[1] µg/L[2]				
Total Uranium (ASTM D5174-97)[3]				0.000504 ± 0.025 (0.385)
Total Uranium, Dissolved[4] (ASTM D5174-97)				0.00134 ± 0.049 (1.927)
Radionuclide Act + Unc (MDC) pCi/L[5]				
Radium-226 (EPA 903.1)	5.28 ± 2.74 (0.955)	2.01 ± 1.33 (1.57)	5.23 ± 2.72	5.53 ± 1.77 (1)
Radium-226, Dissolved (EPA 903.1)	8.18 ± 2.99 (0.693)	2.18 ± 1.53 (0.739)	3.2 ± 1.78	6.66 ± 1.93 (1.41)
Radium-228 (EPA 904.0)	4.56 ± 9.54 (17.7)	1.77 ± 1.07 (1.79)	5.91 ± 2.09	14.3 ± 2.93 (1.35)
Radium-228, Dissolved (EPA 904.0)	5.89 ± 2.07 (2.91)	2.44 ± 0.757 (0.975)	1.39 ± 0.599	5.06 ± 1.28 (1.24)
Total Uranium (EPA 908.0)	0.193 ± 1.56 (2.96)	0.614 ± 0.343 (0.426)	0.116 ± 0.316	
Total Uranium, Dissolved (EPA 908.0)	1.53 ± 2.02 (3.54)	0.591 ± 0.585 (0.957)	0.48 ± 0.302	
Thorium-228 (HSL-300)				
Thorium-228, Dissolved (HSL-300)				
Thorium-230 (HSL-300)				
Thorium-230, Dissolved (HSL-300)				
Thorium-232 (HSL-300)				
Thorium-232, Dissolved (HSL-300)				
Uranium-234 (HSL-300)				
Uranium-234, Dissolved (HSL-300)				
Uranium-235 (HSL-300)				
Uranium-235, Dissolved (HSL-300)				
Uranium-238 (HSL-300)				
Uranium-238, Dissolved (HSL-300)				
Radionuclide Act + Unc (MDC) pCi/L (EPA 901.1 Results)[6]				
Actinium-228 (EPA 901.1)	17.541 ± 17.493 (17.65)	0 ± 8.573 (26.41)	10.776 ± 34.683	0 ± 17.194 (35.08)
Actinium-228, Dissolved (EPA 901.1)	5.463 ± 32.949 (39.03)	5.495 ± 33.532 (40.65)	3.804 ± 17.596	14.281 ± 46.498 (53.5)
Bismuth-212 (EPA 901.1)	38.582 ± 42.687 (84.23)	30.168 ± 59.459 (63.33)	58.102 ± 97.572	0 ± 53.601 (122.7)
Bismuth-212, Dissolved (EPA 901.1)	47.042 ± 96.215 (110.5)	-11.417 ± 121.460 (143)	43.731 ± 57.135	0 ± 48.640 (222.5)
Bismuth-214 (EPA 901.1)	13.416 ± 10.258 (10.25)	187.6 ± 25.829 (14.03)	154.27 ± 30.831	1106.9 ± 123.850 (20.77)
Bismuth-214, Dissolved (EPA 901.1)	2.076 ± 14.454 (18.68)	186.6 ± 33.274 (18.34)	145.06 ± 23.309	798.53 ± 99.899 (28.49)
Cesium-134 (EPA 901.1)	0.000 ± 0.810 (4.94)	3.434 ± 2.866 (4.404)	8.259 ± 7.104	2.595 ± 3.763 (11.05)
Cesium-134, Dissolved (EPA 901.1)	1.095 ± 6.935 (7.908)	0 ± 3.167 (8.765)	0 ± 0.959	0 ± 5.270 (14.83)
Cesium-137 (EPA 901.1)	-1.395 ± 5.178 (5.633)	-0.228 ± 5.483 (6.02)	2.377 ± 8.089	-1.193 ± 8.405 (8.983)
Cesium-137, Dissolved (EPA 901.1)	0.611 ± 6.156 (7.542)	5.015 ± 7.079 (7.867)	0 ± 1.055	-3.804 ± 14.260 (15.98)
Lead-212 (EPA 901.1)	3.737 ± 7.582 (9.19)	61.562 ± 30.991 (12.31)	29.119 ± 16.362	309.97 ± 87.646 (22.65)
Lead-212, Dissolved (EPA 901.1)	0.000 ± 10.106 (21.56)	37.399 ± 19.614 (19.28)	31.287 ± 23.355	178.78 ± 39.984 (28.81)
Lead-214 (EPA 901.1)	19.924 ± 8.571 (8.903)	217.34 ± 30.060 (13.67)	147.5 ± 32.185	1216.5 ± 136.370 (24.36)
Lead-214, Dissolved (EPA 901.1)	6.667 ± 16.000 (20.23)	207.44 ± 34.340 (18.03)	177.92 ± 26.174	786.62 ± 96.671 (30.4)
Potassium-40 (EPA 901.1)	647.540 ± 105.840 (52.18)	548.59 ± 108.050 (62.44)	537.71 ± 148.160	739.66 ± 132.930 (77.04)
Potassium-40, Dissolved (EPA 901.1)	639.070 ± 153.790 (124.2)	490.62 ± 134.080 (115)	321.96 ± 81.245	826.03 ± 184.780 (120.8)
Radium-226 (EPA 901.1)	0.000 ± 100.770 (132.9)	130.46 ± 144.770 (166.1)	0 ± 138.530	81.964 ± 235.760 (275.8)
Radium-226, Dissolved (EPA 901.1)	0.000 ± 97.219 (216.5)	0 ± 122.620 (261.2)	0 ± 102.610	0 ± 179.110 (347)
Radium-228 (EPA 901.1)	17.541 ± 17.493 (17.65)	0 ± 8.573 (26.41)	10.776 ± 34.683	0 ± 17.194 (35.08)
Radium-228, Dissolved (EPA 901.1)	5.463 ± 32.949 (39.03)	5.495 ± 33.532 (40.65)	3.804 ± 17.596	14.281 ± 46.498 (53.5)
Thallium-208 (EPA 901.1)	0.000 ± 1.424 (5.25)	0 ± 2.534 (7.32)	1.63 ± 8.993	0 ± 4.425 (9.793)
Thallium-208, Dissolved (EPA 901.1)	6.782 ± 6.436 (7.219)	0 ± 2.153 (12.6)	0.027 ± 5.667	0 ± 5.426 (20.19)
Thorium-232 (EPA 901.1)	456.960 ± 7629.000 (9482)	1694.6 ± 6765.400 (10880)	2951.8 ± 4927.800	0 ± 4402.600 (18270)
Thorium-232, Dissolved (EPA 901.1)	1200.200 ± 4311.000 (5327)	779.8 ± 5154.500 (6331)	3458.1 ± 8470.400	291.94 ± 7377.000 (9034)
Thorium-234 (EPA 901.1)	0.000 ± 262.560 (546.2)	59.243 ± 95.154 (659.1)	60.122 ± 291.050	0 ± 419.120 (1009)
Thorium-234, Dissolved (EPA 901.1)	0.000 ± 112.960 (342.3)	124.85 ± 273.210 (339.5)	78.099 ± 86.070	0 ± 259.160 (524.7)
Uranium-235 (EPA 901.1)	2.588 ± 29.568 (36.34)	7.227 ± 40.848 (50.33)		
Uranium-235, Dissolved (EPA 901.1)	0.000 ± 27.134 (65.77)	0 ± 39.697 (76.27)		
Uranium-238 (EPA 901.1)	36.811 ± 96.460 (119.8)	85.989 ± 129.890 (160.3)		
Uranium-238, Dissolved (EPA 901.1)	15.997 ± 130.620 (166.1)	0 ± 94.348 (196.4)		

Notes:

1.) Act + Unc (MDC) = Activity ± Uncertainty (Minimum Detectable Concentration)

2.) µg/L = micrograms per liter

3.) Each of EPA 901.1, HSL-300, EPA 903.1, EPA 904.0, ASTM D5174-97, and EPA 908.0 are laboratory analysis methods

4.) Dissolved - indicates sample filtered with 0.45 micron filter prior to analysis.

5.) pCi/L = picocuries per liter

6.) The EPA 901.1 method results are for non-quantitative purposes only due to the method's high degree of uncertainty.

Exhibit F - Chemung County Landfill Leachate Sample Analysis 2012-2017

Parameter	Cell 4 Primary Leachate 1/11/2017	Cell 4 Primary Leachate 11/2/2017	Cell 5 Primary Leachate 1/11/2017	Cell 5 Primary Leachate 11/2/2017
Field Parameters				
Field pH (std. units)	7.75	7.93	6.29	5.86
ORP (mV)	82.4	-39.2	78.6	-201.8
Specific Conductivity (us/cm)	21467	20518	2107	12108
Temperature (deg. C)	17.25	18.3	6.29	16.5
Turbidity (NTU)	16.2	12.8	12.3	152
Radionuclide Act + Unc (MDC)[1] µg/L[2]				
Total Uranium (ASTM D5174-97)[3]	0.000274 ± 0.005 (0.385)	0.000672 ± 0.033 (0.385)	0.00142 ± 0.028 (0.385)	0.000079 ± 0.016 (0.385)
Total Uranium, Dissolved[4] (ASTM D5174-97)	0.000162 ± 0.003 (0.385)	0.000963 ± 0.045 (0.385)	0.00208 ± 0.042 (0.385)	0.000235 ± 0.011 (0.385)
Radionuclide Act + Unc (MDC) pCi/L[5]				
Radium-226 (EPA 903.1)	2.05 ± 2.03 (3.08)	4.89 ± 1.88 (1.42)	0.509 ± 0.399 (0.469)	2.25 ± 1.18 (1.16)
Radium-226, Dissolved (EPA 903.1)	4.4 ± 1.20 (0.499)	2.41 ± 1.53 (1.93)	0.626 ± 0.497 (0.646)	1.93 ± 1.41 (1.94)
Radium-228 (EPA 904.0)	8.59 ± 2.26 (2.48)	4.84 ± 1.23 (1.1)	1.43 ± 0.708 (1.19)	8.26 ± 1.90 (1.37)
Radium-228, Dissolved (EPA 904.0)	5.17 ± 1.34 (1.31)	3.11 ± 0.933 (1.02)	0.502 ± 0.555 (1.16)	2.59 ± 1.45 (2.61)
Total Uranium (EPA 908.0)				
Total Uranium, Dissolved (EPA 908.0)				
Thorium-228 (HSL-300)				
Thorium-228, Dissolved (HSL-300)				
Thorium-230 (HSL-300)				
Thorium-230, Dissolved (HSL-300)				
Thorium-232 (HSL-300)				
Thorium-232, Dissolved (HSL-300)				
Uranium-234 (HSL-300)				
Uranium-234, Dissolved (HSL-300)				
Uranium-235 (HSL-300)				
Uranium-235, Dissolved (HSL-300)				
Uranium-238 (HSL-300)				
Uranium-238, Dissolved (HSL-300)				
Radionuclide Act + Unc (MDC) pCi/L (EPA 901.1 Results)[6]				
Actinium-228 (EPA 901.1)	7.922 ± 24.467 (25.4)	7.815 ± 17.949 (18.82)	0.000 ± 15.416 (37.91)	0 ± 5.750 (21.72)
Actinium-228, Dissolved (EPA 901.1)	47.601 ± 22.389 (21.2)	0 ± 21.306 (51.93)	36.128 ± 41.448 (44.4)	5.074 ± 36.768 (43.45)
Bismuth-212 (EPA 901.1)	-6.595 ± 71.139 (78.24)	0 ± 37.305 (81.94)	-37.313 ± 115.720 (122.9)	0 ± 24.950 (66.84)
Bismuth-212, Dissolved (EPA 901.1)	0.000 ± 64.471 (156.9)	0 ± 16.440 (158.7)	0.000 ± 78.817 (174)	0 ± 49.318 (193.8)
Bismuth-214 (EPA 901.1)	295.85 ± 39.015 (14.54)	121.09 ± 21.147 (12.31)	1121.8 ± 125.350 (19.2)	87.142 ± 15.329 (12.51)
Bismuth-214, Dissolved (EPA 901.1)	419.24 ± 54.878 (20.51)	411.12 ± 58.873 (24.92)	822.27 ± 99.895 (26.51)	417.56 ± 59.612 (24.92)
Cesium-134 (EPA 901.1)	0.000 ± 2.391 (8.428)	0.395 ± 5.883 (6.305)	0.000 ± 2.244 (11.5)	2.12 ± 4.262 (4.544)
Cesium-134, Dissolved (EPA 901.1)	0.000 ± 5.095 (10.81)	0 ± 2.326 (14.84)	1.864 ± 11.105 (12.46)	6.405 ± 8.685 (9.113)
Cesium-137 (EPA 901.1)	0.000 ± 2.066 (6.787)	0 ± 1.554 (6.611)	0.000 ± 3.445 (9.266)	0 ± 1.056 (5.061)
Cesium-137, Dissolved (EPA 901.1)	0.000 ± 2.385 (12.58)	0.952 ± 10.009 (11.63)	0.000 ± 4.127 (13.15)	0 ± 2.826 (13.45)
Lead-212 (EPA 901.1)	61.698 ± 34.623 (14.06)	46.618 ± 19.646 (10.48)	271.25 ± 56.691 (21.8)	16.678 ± 18.661 (11.11)
Lead-212, Dissolved (EPA 901.1)	113.03 ± 29.478 (21.93)	131.22 ± 34.318 (22.95)	206.72 ± 44.087 (26.52)	82.192 ± 23.530 (22.18)
Lead-214 (EPA 901.1)	327.89 ± 42.738 (16.34)	134.57 ± 20.297 (11.34)	1178.1 ± 131.730 (22.72)	112.24 ± 19.025 (11.37)
Lead-214, Dissolved (EPA 901.1)	453.51 ± 57.749 (21.99)	385.96 ± 54.341 (29.18)	836.52 ± 99.625 (27.44)	378.25 ± 53.770 (24.38)
Potassium-40 (EPA 901.1)	657.68 ± 119.830 (66.28)	626.36 ± 107.160 (53.83)	52.752 ± 89.716 (86.7)	361.14 ± 84.663 (58.73)
Potassium-40, Dissolved (EPA 901.1)	583.31 ± 146.910 (126.3)	707.3 ± 160.040 (113.9)	0.000 ± 73.963 (180)	169.84 ± 180.950 (192.1)
Radium-226 (EPA 901.1)	0.000 ± 79.632 (192.3)	0 ± 70.040 (159.3)	0.000 ± 73.104 (286.9)	0 ± 86.309 (142.8)
Radium-226, Dissolved (EPA 901.1)	0.000 ± 162.760 (277.3)	71.926 ± 218.940 (268.5)	0.000 ± 206.960 (342.1)	148.79 ± 213.390 (257.6)
Radium-228 (EPA 901.1)	7.922 ± 24.467 (25.4)	7.815 ± 17.949 (18.82)	0.000 ± 15.416 (37.91)	0 ± 5.750 (21.72)
Radium-228, Dissolved (EPA 901.1)	47.601 ± 22.389 (21.2)	0 ± 21.306 (51.93)	36.128 ± 41.448 (44.4)	5.074 ± 36.768 (43.45)
Thallium-208 (EPA 901.1)	0.000 ± 1.940 (7.754)	0 ± 1.509 (7.255)	0.000 ± 8.289 (10.49)	3.054 ± 3.647 (7.255)
Thallium-208, Dissolved (EPA 901.1)	3.302 ± 10.705 (12.38)	0 ± 5.694 (12.21)	0.000 ± 6.658 (16.28)	3.781 ± 10.708 (12.21)
Thorium-232 (EPA 901.1)	0.000 ± 4993.400 (11830)	3303.6 ± 8324.400 (10090)	0.000 ± 8315.100 (18160)	0 ± 3659.000 (11430)
Thorium-232, Dissolved (EPA 901.1)	3836.6 ± 5752.100 (6903)	1297.5 ± 5564.900 (6830)	4694.6 ± 7038.500 (8446)	2432.8 ± 6364.500 (7743)
Thorium-234 (EPA 901.1)	85.346 ± 103.910 (689.3)	85.747 ± 468.390 (589.9)	46.817 ± 778.480 (972.1)	0 ± 210.740 (577.1)
Thorium-234, Dissolved (EPA 901.1)	3.481 ± 331.010 (405.7)	52.204 ± 312.580 (389.2)	0.000 ± 184.240 (526.6)	54.947 ± 364.780 (450.9)
Uranium-235 (EPA 901.1)				
Uranium-235, Dissolved (EPA 901.1)				
Uranium-238 (EPA 901.1)				
Uranium-238, Dissolved (EPA 901.1)				

Notes:

1.) Act + Unc (MDC) = Activity ± Uncertainty (Minimum Detectable Concentration)

2.) µg/L = micrograms per liter

3.) Each of EPA 901.1, HSL-300, EPA 903.1, EPA 904.0, ASTM D5174-97, and EPA 908.0 are laboratory analysis methods

4.) Dissolved - Indicates sample filtered with 0.45 micron filter prior to analysis.

5.) pCi/L = picocuries per liter

6.) The EPA 901.1 method results are for non-quantitative purposes only due to the method's high degree of uncertainty.

EXHIBIT G

Exhibit G - Hakes C&D Landfill February 2018 Leachate Sample Analysis

Parameter	Cell 3 Leachate 2/27/2018	Cell 4 Leachate 2/27/2018	Cell 8 Leachate 2/27/2018	LCS 2/27/2018
Field Parameters				
Field pH (std. units)	6.69	6.86	6.47	6.92
ORP (mV)	30.6	11.6	10	199.4
Specific Conductivity (us/cm)	6191	6379	1577	3427
Temperature (deg. C)	17	18.3	16	9.3
Turbidity (NTU)	20.6	76.1	111	32.9
Radionuclide Act + Unc (MDC)[1] pCi/L[2]				
Radium-226, Dissolved[3] (EPA 903.1)[4]	1.37 ± 0.46 (0.23)	1.36 ± 0.44 (0.11)	0.59 ± 0.27 (0.23)	0.95 ± 0.35 (0.21)
Radium-226, Total (EPA 903.1)	2.67 ± 0.77 (0.18)	2.16 ± 0.64 (0.21)	0.89 ± 0.34 (0.2)	0.82 ± 0.33 (0.23)
Radium-228, Dissolved (EPA 904.0)	1.11 ± 0.44 (0.65)	0.71 ± 0.37 (0.64)	0.96 ± 0.4 (0.63)	1.29 ± 0.48 (0.68)
Radium-228, Total (EPA 904.0)	0.75 ± 0.37 (0.65)	1.7 ± 0.56 (0.71)	0.7 ± 0.38 (0.68)	0.81 ± 0.39 (0.66)
Total Uranium, Dissolved (HASL-300)	0.35 ± 0.16 (0.12)	1.15 ± 0.28 (0.11)	0.5 ± 0.2 (0.15)	1.08 ± 0.26 (0.13)
Total Uranium, Total (HASL-300)	0.37 ± 0.15 (0.12)	1.14 ± 0.35 (0.18)	0.52 ± 0.16 (0.06)	0.92 ± 0.23 (0.11)
Uranium-234, Dissolved (HASL-300)	0.2 ± 0.11 (0.1)	0.61 ± 0.2 (0.08)	0.28 ± 0.14 (0.13)	0.51 ± 0.18 (0.07)
Uranium-234, Total (HASL-300)	0.17 ± 0.1 (0.08)	0.65 ± 0.26 (0.11)	0.25 ± 0.11 (0.03)	0.51 ± 0.18 (0.09)
Uranium-235, Dissolved (HASL-300)	0.01 ± 0.058 (0.086)	0.044 ± 0.054 (0.039)	0 ± 0.063 (0.047)	0.082 ± 0.073 (0.08)
Uranium-235, Total (HASL-300)	0.039 ± 0.055 (0.082)	0.015 ± 0.089 (0.133)	0.052 ± 0.053 (0.035)	0.021 ± 0.048 (0.071)
Uranium-238, Dissolved (HASL-300)	0.141 ± 0.092 (0.073)	0.49 ± 0.18 (0.09)	0.22 ± 0.12 (0.11)	0.48 ± 0.18 (0.12)
Uranium-238, Total (HASL-300)	0.16 ± 0.1 (0.1)	0.47 ± 0.22 (0.16)	0.22 ± 0.11 (0.06)	0.39 ± 0.15 (0.07)
Lead-210, Dissolved (SOP 704)	0.11 ± 0.58 (0.97)	0.52 ± 0.61 (0.98)	0.36 ± 0.6 (0.98)	0.3 ± 0.57 (0.94)
Lead-210, Total (SOP 704)	0.62 ± 0.57 (0.9)	0.59 ± 0.57 (0.9)	0.19 ± 0.59 (0.98)	0.52 ± 0.61 (0.98)
Radionuclide Act + Unc (MDC) pCi/L (EPA 901.1 Results)[5]				
Actinium-228, Dissolved (EPA 901.1)	-1 ± 30 (52)	5 ± 27 (46)	10 ± 28 (48)	-25 ± 30 (54)
Actinium-228, Total (EPA 901.1)	14 ± 26 (44)	1 ± 13 (22)	-9 ± 26 (46)	12 ± 23 (38)
Bismuth-212, Dissolved (EPA 901.1)	8 ± 70 (122)	31 ± 79 (133)	21 ± 81 (138)	21 ± 72 (122)
Bismuth-212, Total (EPA 901.1)	26 ± 79 (136)	22 ± 47 (79)	25 ± 80 (135)	3 ± 69 (120)
Bismuth-214, Dissolved (EPA 901.1)	6 ± 15 (25)	-5 ± 18 (31)	5 ± 17 (28)	3 ± 13 (22)
Bismuth-214, Total (EPA 901.1)	10 ± 12 (19)	-2 ± 11 (18)	10 ± 21 (35)	9 ± 14 (24)
Cesium-134, Dissolved (EPA 901.1)	-6.7 ± 6.2 (11.1)	7.6 ± 5.7 (8.9)	-4.4 ± 6 (10.6)	0.9 ± 4.8 (8.2)
Cesium-134, Total (EPA 901.1)	-2.4 ± 5.2 (9.4)	-4.5 ± 3.2 (5.5)	-3.4 ± 5.5 (9.7)	-3.6 ± 4.5 (8.2)
Cesium-137, Dissolved (EPA 901.1)	-0.6 ± 5.2 (9.1)	-2 ± 4.9 (8.8)	1.1 ± 5.5 (9.4)	-3.2 ± 5.4 (9.8)
Cesium-137, Total (EPA 901.1)	-1.8 ± 5 (9)	-2 ± 2.6 (4.7)	0.5 ± 5.6 (9.7)	0.4 ± 4.6 (7.9)
Lead-212, Dissolved (EPA 901.1)	-1 ± 14 (23)	1 ± 13 (23)	5.1 ± 9.9 (16.4)	6 ± 11 (18)
Lead-212, Total (EPA 901.1)	-3 ± 11 (18)	-1.7 ± 6.2 (10.5)	0.1 ± 9.9 (16.7)	5.3 ± 8.6 (14.2)
Lead-214, Dissolved (EPA 901.1)	10 ± 11 (17)	-2 ± 13 (22)	5 ± 13 (21)	6 ± 13 (22)
Lead-214, Total (EPA 901.1)	1 ± 12 (20)	3 ± 9.9 (16.4)	11.2 ± 9.7 (15.5)	7 ± 9.5 (15.5)
Potassium-40, Dissolved (EPA 901.1)	92 ± 96 (156)	140 ± 100 (160)	16 ± 97 (167)	30 ± 120 (190)
Potassium-40, Total (EPA 901.1)	73 ± 96 (158)	74 ± 51 (81)	-110 ± 120 (230)	63 ± 83 (137)
Radium-226, Dissolved (EPA 901.1)	10 ± 140 (230)	-40 ± 140 (240)	30 ± 110 (180)	27 ± 94 (157)
Radium-226, Total (EPA 901.1)	-10 ± 100 (170)	50 ± 83 (136)	30 ± 110 (190)	60 ± 86 (142)
Radium-228, Dissolved (EPA 901.1)	-1 ± 30 (52)	5 ± 27 (46)	10 ± 28 (48)	-25 ± 30 (54)
Radium-228, Total (EPA 901.1)	14 ± 26 (44)	1 ± 13 (22)	-9 ± 26 (46)	12 ± 23 (38)
Thallium-208, Dissolved (EPA 901.1)	6.6 ± 6 (9.5)	-6.8 ± 8.7 (15.2)	2.7 ± 8.1 (13.6)	3.9 ± 5.5 (9)
Thallium-208, Total (EPA 901.1)	2.5 ± 7 (11.8)	-1.4 ± 3.6 (6.2)	1.5 ± 8.8 (14.9)	1.7 ± 6.3 (10.7)
Thorium-227, Dissolved (EPA 901.1)	1 ± 39 (66)	-60 ± 41 (75)	9 ± 41 (68)	-6 ± 25 (43)
Thorium-227, Total (EPA 901.1)	15 ± 33 (54)	-7 ± 22 (37)	14 ± 26 (43)	-3 ± 19 (34)
Thorium-232, Dissolved (EPA 901.1)	-1 ± 30 (52)	5 ± 27 (46)	10 ± 28 (48)	-25 ± 30 (54)
Thorium-232, Total (EPA 901.1)	14 ± 26 (44)	1 ± 13 (22)	-9 ± 26 (46)	12 ± 23 (38)
Thorium-234, Dissolved (EPA 901.1)	70 ± 200 (330)	60 ± 160 (260)	-40 ± 100 (180)	34 ± 66 (110)
Thorium-234, Total (EPA 901.1)	-15 ± 68 (114)	-17 ± 77 (130)	10 ± 130 (220)	0 ± 59 (100)

Notes:

1.) Act + Unc (MDC) = Activity ± Uncertainty (Minimum Detectable Concentration)

2.) pCi/L = picocuries per liter

3.) Dissolved - Indicates sample filtered with 0.45 micron filter prior to analysis.

4.) Each of EPA 901.1, EPA 903.1, EPA 904.0, HASL-300, and SOP 704 are laboratory analysis methods.

5.) The EPA 901.1 method results are for non-quantitative purposes only due to the method's high degree of uncertainty.

EXHIBIT H

TRUCK MONITOR CORRELATION REPORT

CASELLA WASTE SYSTEMS, INC.

DATE OF SURVEY: MARCH 26, 2015

Prepared by:

CoPhysics Corporation
1 Commercial Drive, Suite 1
Florida, NY 10921

Survey Manager: Theodore E Rahon Date: 6/7/15

Theodore E. Rahon, Ph.D.
Certified Health Physicist

1 Introduction

Gamma radiation detectors are routinely used at landfill weighing scales to determine if entering trucks contain unauthorized radioactive materials. However, readings on the monitors cannot easily be related to the quantity of radioactive materials in loads. Computer algorithms to estimate radioactivity concentrations from gamma emissions from trucks have numerous uncertain input variables such as load density, truck wall thickness, container to detector geometry, and radionuclide series equilibrium. Therefore, an actual in-field correlation test was performed to more accurately relate gamma count rate to radionuclide concentration in a load.

The specific situation studied during this test is the estimation of the radium-226 concentration in relatively uniform material.

2 Methods

2.1 General Method

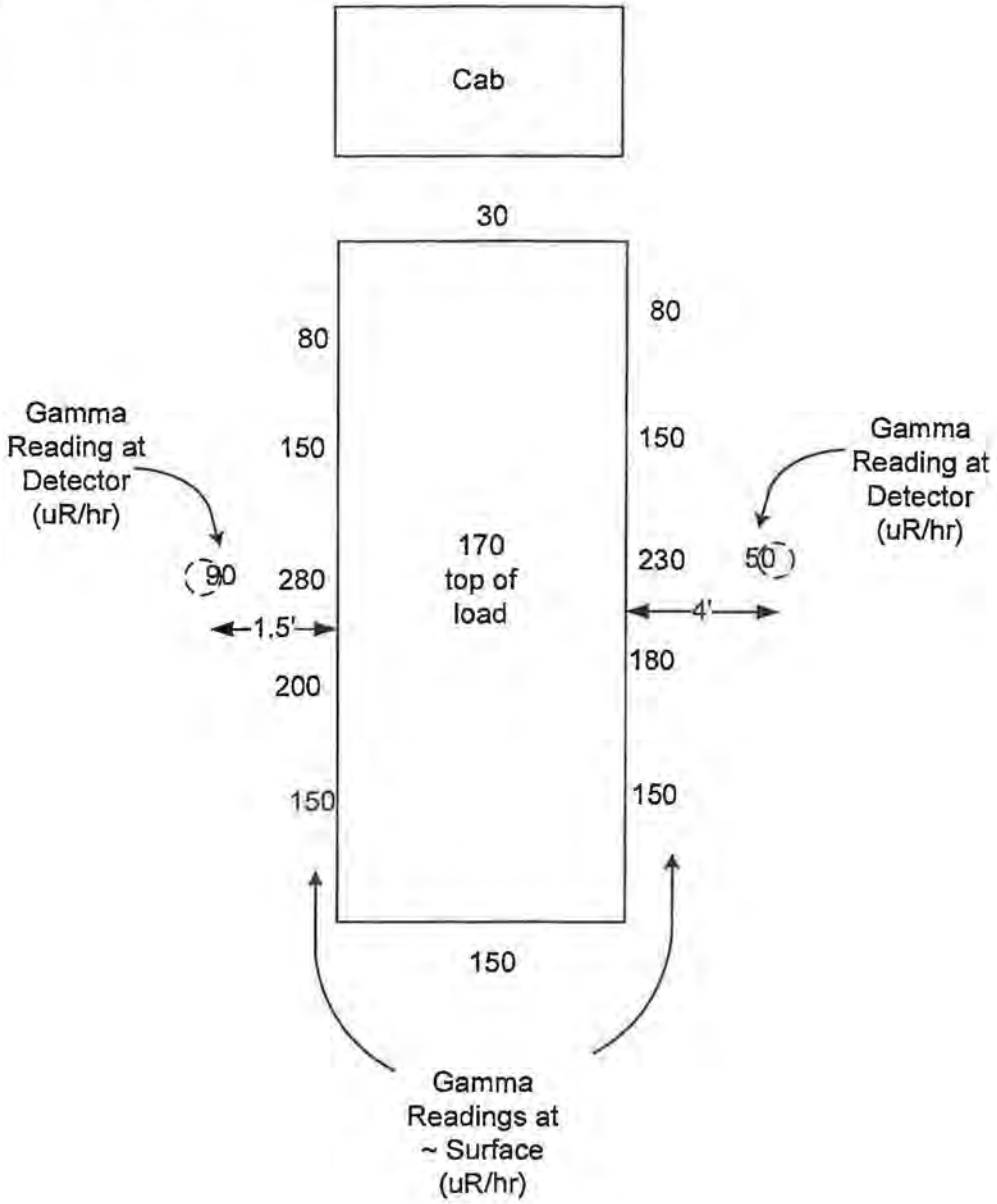
A Ludlum Model 375P-1000 gamma radiation monitor at the McKean County, Pa. landfill was used to measure gamma emissions from a roll-off filled with radium-bearing sludge cake. The sludge cake was very uniform, having been de-watered and pressed into 1" thick plates which were broken into chunks that filled the 30-cubic yard roll-off. The brown material had a moderately dry, clay-like consistency. Both visual observation and a perimeter scan with a hand-held uR meter indicated that the material was relatively uniform. The load contained 27,680 lbs of sludge cake.

First, the radiation monitor background was recorded (3.5 KCPS) then the roll-off was moved in between the detectors. The resultant reading was recorded (36.8 KCPS). Gamma exposure rates at the two detectors were also checked with a hand held uR meter. An empty roll-off was then used to record an "empty truck" background reading on the monitor (2.4 KCPS).

A composite sample of the sludge cake was collected from 4 spots near the center of the load (approximately where the detectors were positioned) and was sent to Pace Laboratories (NELAP-certified) for gamma spectroscopic analysis after 21-day radon progeny ingrowth.

3 Results

The gamma readings at the surface of the roll-off and at the Model 1000 detectors are shown in the figure below:



Readings were performed with the following instrument:

Manufacturer	Meter Model	Serial #	Detector or Meter Type	Calib. Date
Ludlum Measurements	12S	77640	NaI-based uR meter	8/28/14

Observations:

The front of the roll-off exhibited far less gamma emission than the middle of load because the front was only partially filled. The middle and rear of the roll-off were completely full. The rear exhibited slightly less than the middle due to the difference in source geometry.

The detectors were positioned at the center (maximum gamma reading) of the roll-off. The truck was not quite centered, being 1.5 feet from the left detector and 4 feet from the right detector. This should not affect the test since the count rate from the detectors are summed.

Readings:

The readings on the Model 375-1000 follow:

Background (no truck present): 3.5 KCPS

Background (empty truck present): 2.5 KCPS

Hot Load Reading (detectors at middle of truck side walls): 36.8 KCPS

Laboratory Results (complete lab report shown in Attachment A):

The pertinent radionuclide concentrations from the sample analysis are also shown below (rounded):

Ra-226 (186 line): 112 +- 15 pCi/g
Bi-214 (609 line): 106 +- 14 pCi/g
Ra-228 (Ac-228 911 line): 15.5 +- 2.7 pCi/g
K-40 : 0.5 +- 5.5 pCi/g

Note: the above concentrations are based on *in situ* mass (sample not dried in the laboratory).

Calculation of Conversion Factor:

= (36.8 KCPS – 2.5 KCPS) / 112 pCi/g = 0.306 KCPS/(pCi/g) over background

4 Conclusion

The result of this test of a 30-yard roll-off, filled to near capacity, resulted in a gamma count rate to radium concentration conversion factor of 0.306 KCPS/(pCi/g) over background.

For a monitor with a background of 3.6 KCPS (the background occurring during the most recent calibration of the Chemung County Landfill monitor), the count rate corresponding to a 25 pCi/g radium-226 investigation level would be (0.306 x 25) + 3.6 = 11.25 KCPS.

Presently the Chemung County monitor's alarm levels are 10 KCPS sum alarm (sum of both detectors) and a sigma alarm of 110 which equates to approximately 7 KCPS depending on truck speed entering the detection area. (The sigma alarm sounds if it detects a rapid increase in count rate even if the sum alarm is not reached.) These alarm settings are well within the 11.25 KCPS level corresponding to 25 pCi/g of radium. Therefore, the present alarm settings at the Chemung County Landfill are sufficient to detect a roll-off containing 25 pCi/g or more of radium-226.

Attachment A – Pace Laboratory

Analysis Report – page 6

Pace Analytical Services, Inc.
1638 Roseytown Road - Suites 2,3,4
Greensburg, PA 15601
(724)850-5600

ANALYTICAL RESULTS - RADIOCHEMISTRY

Project: McKean Monitor Test
Pace Project No.: 30145525

Sample: 032615A Lab ID: 30145525001 Collected: 03/26/15 11:44 Received: 04/14/15 09:55 Matrix: Solid
PWS: Site ID: Sample Type:

Results reported on a "dry-weight" basis

Parameters	Method	Act ± Unc (MDC) Carr Trac	Units	Analyzed	CAS No.	Qual
Bismuth-212	EPA 901.1	15.936 ± 5.494 (5.320) C:NA T:NA	pCi/g	05/20/15 15:13	14913-49-6	
Bismuth-214	EPA 901.1	105.260 ± 14.260 (1.160) C:NA T:NA	pCi/g	05/20/15 15:13	14733-03-0	
Lead-212	EPA 901.1	12.398 ± 1.899 (1.114) C:NA T:NA	pCi/g	05/20/15 15:13	15092-94-1	
Lead-214	EPA 901.1	116.180 ± 15.563 (1.450) C:NA T:NA	pCi/g	05/20/15 15:13	15067-28-4	
Potassium-40	EPA 901.1	0.497 ± 5.475 (4.931) C:NA T:NA	pCi/g	05/20/15 15:13	13966-00-2	
Radium-226	EPA 901.1	111.950 ± 14.905 (1.160) C:NA T:NA	pCi/g	05/20/15 15:13	13982-63-3	
Radium-228	EPA 901.1	15.476 ± 2.686 (1.660) C:NA T:NA	pCi/g	05/20/15 15:13	15262-20-1	
Thallium-208	EPA 901.1	4.768 ± 1.015 (0.645) C:NA T:NA	pCi/g	05/20/15 15:13	14913-50-9	
Thorium-234	EPA 901.1	11.445 ± 11.278 (18.300) C:NA T:NA	pCi/g	05/20/15 15:13	15065-10-8	
Uranium-235	EPA 901.1	8.633 ± 1.515 (0.948) C:NA T:NA	pCi/g	05/20/15 15:13	15117-96-1	

REPORT OF LABORATORY ANALYSIS

EXHIBIT I

RADIATION RESEARCH 182, 463–474 (2014)
0033-7587/14 $15.00

DOI: 10.1667/RR13829.1

COMMENTARY

Estimating Risk of Low Radiation Doses – A Critical Review of the BEIR VII Report and its Use of the Linear No-Threshold (LNT) Hypothesis

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Calabrese, E. J. and O'Connor, M. K. Estimating Risk of Low Radiation Doses – A Critical Review of the BEIR VII Report and its Use of the Linear No-Threshold (LNT) Hypothesis. *Radiat. Res.* 182, 463–474 (2014).

This article explores the origin of the linear no-threshold (LNT) dose-response model and how it came to be used in cancer risk assessment worldwide. Following this historical appraisal is an evaluation of the LNT model, within the framework of the BEIR VII report of the National Academy of Sciences, on the health effects of ionizing radiation. The final section of this article provides an assessment of the LNT model's capacity to make accurate predictions of risk in the low-dose zone based on recent molecular mechanistic findings and epidemiological methods, with particular emphasis on the limitations of epidemiological studies to estimate risks in the low-dose zone.

INTRODUCTION

In the U.S., it is well recognized that the increasing use of diagnostic imaging procedures over the last two decades has led to a significant increase in the collective radiation dose to the public (*1*). This increased dose has generated concern among the public and regulatory authorities and has been fueled in no small part by numerous scientific articles claiming that this increase will result in tens of thousands of excess cancer occurrences per year (*2–4*). These estimates of excess cancers are underpinned by one key document, the BEIR VII report (*5*) (or one of its predecessors), which itself has as its foundation the use of the linear no-threshold (LNT) dose-response model. The LNT model is used to estimate cancer risks from exposures to low doses of ionizing radiation and chemical carcinogens. Thus, in examining how estimates of cancer fatalities are obtained it is important to understand the origins, strengths and limitations of both the BEIR VII report and the LNT model on which it is based. Around the time that the BEIR VII report was published, the French Academy of Sciences also published a comparable evaluation of carcinogenic risks of ionizing radiation. The French Academy report emphasized the significance of low-dose induced adaptive responses and came to a very different conclusion than the BEIR VII report, and suggested that extrapolation from high to low doses could not be reliably done, thereby challenging an LNT model use in cancer risk assessment (*6*).

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LNT MODEL AND BEIR: HISTORICAL FOUNDATIONS

About a year after Muller's 1927 report (*7*) that X rays could induce mutations in the germ cells of male fruit flies, two University of California physical chemists, Olson and Lewis, proposed the LNT model (*8*) to account for genetic changes in the genome from background ionizing radiation, thereby offering a mechanistic explanation of Darwin's theory of evolution. This LNT mutational explanation from cosmic/background radiation as the driver of evolutionary change was soon widely rejected (*9*) and remains so to this day since mutational changes in multiple experimental models were not effectively produced even at radiation doses several orders of magnitude greater than background radiation (*10*).

Despite the inability of background ionizing radiation to induce ostensible mutational changes in these studies, the LNT model was adopted by Hermann J. Muller and the radiation genetics community in an attempt to predict the effects of ionizing radiation on the genome (*11, 12*). They theorized various hit scenarios, developed mathematical equations to describe theoretical mutational responses and then matched their predictions to the mutation data of Muller and other researchers. Linear dose responses at very high doses, several hundred thousand-fold greater than background, visually matched their single hit model. As a

result of this convergence of the LNT model and high-dose data, these researchers linked the single-hit concept with the earlier LNT model, and gave the LNT a mechanism, even if ill-defined (*13*). Thus, the LNT model was reintroduced even though the original reason for its rejection (i.e., failure to detect mutations at low doses) was still valid.

Muller and his radiation geneticist colleagues worked over the next two decades to get major national and international committees to drop their historical reliance on a threshold dose-response model and to adopt the LNT single-hit model for risk assessment (*14, 15*). Even though they repeatedly failed in this effort, they finally achieved a long desired success when in 1955 the National Academy of Sciences (NAS) established the first committee on the Biological Effects of Atomic Radiation (BEAR), comprised of 12 radiation geneticists, including Muller, who persuaded the committee to adopt the LNT model for risk estimation (*16*). After the first two BEAR reports, in 1956 and 1960, the committee was essentially reformulated as the Biological Effects of Ionizing Radiation (BEIR) Committee. Subsequent BEIR reports up to and including the BEIR VII report continued to use the LNT model or variations thereof as the cornerstone for risk assessment. Given the prestige of the National Academy of Sciences, the recommendation to use the LNT model was adopted quickly in the U.S. and elsewhere, and generalized from the narrow area of genome risk to those involving somatic cells, with application to cancer risk assessment. When the U.S. Environmental Protection Agency (EPA) cancer risk policy was first developed in 1976, the EPA turned to the NAS for a suitable model for risk assessment and subsequently adopted the LNT model as its centerpiece for its cancer risk policy, providing the key foundation for cancer risk assessment guidelines starting in 1977, and continuing to the present day. Furthermore, the LNT model provides a fundamental underpinning for the Precautionary Principle that has captured regulatory agencies worldwide, which states that if an agent has a suspected risk of causing harm to the public, in the absence of scientific consensus that the agent is harmful, the burden of proof that it is not harmful falls on those overseeing the agent. In some legal systems, such as that of the European Union, the application of the precautionary principle has been made a statutory requirement in some areas of law.

THE CASE FOR AND AGAINST THE LNT MODEL

A quick Google search of "radiation risks from medical procedures" returns approximately 22 million entries. A similar search on the risks of dying in an automobile accident (9 million hits) and smoking (23 million hits) are lower or comparable despite the daily reminder of deaths from auto accidents and volumes of scientific studies documenting the actual fatalities from smoking. By comparison, deaths from low doses of ionizing radiation associated with medical imaging procedures are for the greater part hypothetical and unproven. So how as a society have we ended up in a position where the fear of ionizing radiation exceeds that of activities that cause measurable fatalities? David Ropeik contributed an interesting Op-Ed article in the *New York Times* (Oct 21, 2013) entitled "Fear vs. Radiation: The Mismatch".[2] In it he discussed our fear of radiation, which stems from our understandable fear of the power of nuclear weapons. He added that "in the 68 years" since Hiroshima and Nagasaki, epidemiological and scientific studies have shown that at doses of less than 100 mSv, radiation causes no detectable elevations in normal rates of illness and disease. Yet, Ropeik states, "The robust evidence that ionizing radiation is a relatively low health risk dramatically contradicts common fears".

In his historical review of the quarrels and arguments that consumed the members of the first BEAR Committee, Professor James Crow from the University of Wisconsin (*17*) concluded that while Muller did not have his way with much of the wording of the Committee report, his major practical recommendation nevertheless prevailed, which was that the standard be set low, in the vicinity of the natural background level. In the years immediately following the BEAR report there were numerous discussions among individuals and in committees, as well as Congressional hearings. Radiation protection became a major concern, resulting in an end to above-ground bomb testing, among other consequences. In the view of Professor Crow, Muller and the radiation geneticists certainly won the day. In retrospect many of the committee members, including Crow, oversold the dangers of radiation, and thus shoulder some of the blame for what now seems to be an irrational emphasis by some scientists, the press, the general public and the regulatory agencies on low-level radiation in comparison to other greater risks. Calabrese has argued that Muller misled the scientific community during his highly influential 1946 Nobel Prize lecture on the nature of the dose response in the low-dose zone, demanding a change to the LNT model while claiming there was no longer any justification to continue to use the threshold (*11, 12, 15, 18, 19*). He appears to have made these remarks with detailed knowledge that the most recent and convincing data (though still unpublished at that time) on the nature of the dose response supported a threshold model. These were data from a Manhattan Project funded study at the University of Rochester under the direction of Curt Stern, a project on which Muller was a consultant. Muller and Stern's insistence that the LNT model was valid led to the data from this project being reinterpreted and constrained to fit the theory (*18, 20–22*). Calabrese (*12, 18, 23*) has shown that Muller and Stern went to considerable lengths to ensure the establishment of the LNT, providing a classic example

[2] Ropeik D. Fear vs. Radiation: The Mismatch. The New York Times. 2013 Oct 21. (www.nytimes.com/2013/10/22/opinion/fear-vs-radiation-the-mismatch.html)

of where the ends (i.e., reduction in exposure) justified the means (i.e., data obfuscation and selective interpretation). Stern further promoted the LNT through key articles in the journal *Genetics* for which he was editor (*21, 22*). Stern also coauthored a key technical note in *Science* supporting the LNT model, but which was devoid of all methods and supporting data [detailed analyses in refs. (*12, 17, 23*)]. Although the missing data was to be presented in a later manuscript, which as it turned out, never happened. Muller's actions have also been recently reviewed by Kesavan (*24*) who found that he made selective citations in his Nobel Prize lecture to buttress the LNT model. For example, Muller cited several studies (*13, 25, 26*) that all used high doses and dose rates and found linearity. However, he did not cite or discuss other articles (*27–30*) that did not support linearity at lower doses and dose rates. From the above brief historical assessment, it can be appreciated that the scientific rigor associated with the validation of LNT was abandoned in the drive to protect the public from what the radiation genetics community saw as the dangers of ionizing radiation.

In recent years societal fears of ionizing radiation have been redirected from events such as Chernobyl and Fukushima (that while headline-grabbing, have little impact on our daily lives), to now focus instead on medical imaging procedures such as CT scans (*3, 4*). Our failure to help the public understand the relatively low health risks associated with radiation is now impacting our daily lives and the decisions that people make on whether or not to undergo recommended vital imaging procedures that can impact their well being. The precautionary principle works well only if the action associated with reducing or eliminating the agent has no harmful effects. The negative consequences of the precautionary principle (i.e., fear of radiation and the consequential failure to use medical imaging to enable early diagnosis of serious medical conditions) seem to have been lost in the rush to eliminate sources of radiation from our lives.

Several articles in the medical literature over the past few years have predicted thousands of cancers and cancer deaths annually in the U.S. population caused by radiation exposures from medical imaging (*3, 4*). These predictions are derived from risk estimates, published in the BEIR VII report (*5*). These risk estimates are speculative with wide confidence intervals, and are based on risk models generated from studies on subjects exposed to high levels of radiation, and then extrapolated to low doses using the LNT model for radiation risk. The weak scientific foundation for these estimates is rarely understood and appreciated by the medical or scientific community, and has not been adequately explained by the BEIR VII Committee. Despite the limitations and uncertainties of cancer estimates in the report, the committee chair, Richard R. Monson, associate dean for professional education and professor of epidemiology, Harvard School of Public Health, commenting at the time of its release, stated unequivocally, "The scientific research base shows that there is no threshold of exposure below which low levels of ionizing radiation can be demonstrated to be harmless or beneficial". The news report from the National Academy of Sciences further stated that the preponderance of evidence supported the LNT model and dismissed any possibility that the LNT model exaggerates adverse health effects. It further stated, "Living at low altitudes, where there is less cosmic radiation, and living and working on the upper floors of buildings, where there is less radon gas – a primary source of natural ionizing radiation – are factors that could decrease exposure" and presumably, the associated risks (*31*). With such dogmatic statements, it should be no surprise that the general public continues to have an irrational fear of ionizing radiation.

It should be noted that the decisions made by the various BEIR Committees are often at odds with those from prior BEIR Committees and may well change with the next iteration of the BEIR process. For example, a review of earlier BEIR reports shows that modest changes in some of the hypotheses used to generate risk estimates can have dramatic consequences. Lifetime excess cancer risks estimated from BEIR III (*32*) and BEIR V (*33*) increased by an order of magnitude as a result of a decision to switch from a linear-quadratic risk model to a linear risk model. For example, instantaneous exposure to 100 mGy in males was estimated to result in 42 deaths per 100,000 in the BEIR III report using the additive risk model. This estimate increased to 660 deaths per 100,000 in the BEIR V report [p. 176, Table 4-4 (*33*)]. Furthermore, while the BEIR III report utilized both an additive risk model and a relative risk model, the BEIR V concluded that only the relative risk model was valid. By the time BEIR VII came out, the committee had reversed direction and was now using a combination of the two models. While the underlying scientific data reviewed by these committees had obviously been updated, there was and is nothing in the published literature indicating that the risks from ionizing radiation are an order of magnitude greater than previously thought.

The next section briefly presents the key studies considered by the most recent BEIR VII Committee in its consideration of the risks associated with low doses of ionizing radiation, and its use of this data in estimating cancer risk from low levels of ionizing radiation. These are balanced against position statements from scientific organizations involved in the use of ionizing radiation, which comment on the dangers to society when hypothetical predictions are made about cancer risks.

SOURCES OF DATA OF STOCHASTIC EFFECTS OF IONIZING RADIATION

The BEIR VII Committee considered four primary sources of data on the stochastic effects of ionizing radiation. These were environmental radiation studies, occupational radiation studies, medical radiation studies and studies on the atomic bomb survivors. Below is a brief review of some of the key studies in each of these areas.

Environmental Studies

Environmental studies included studies of populations living in areas of high natural background radiation, studies of populations exposed to fallout from nuclear accidents (Chernobyl) and populations living near nuclear power facilities. The largest study of populations living near nuclear facilities was that of Jablon *et al.* (*34*) and involved 1,800,000 cancer deaths between 1950–1984 in 107 counties in the U.S. The incidence of death due to leukemia or other cancers was found to be no more frequent in the study counties than in the control counties. In fact, the relative risk of leukemia dropped after the startup of the nuclear facilities. However, because the study was limited by the correlational approach and the large size of the geographic areas (counties) used, it could not prove the absence of a small effect and was considered unsuitable for risk estimation.

There were four studies of populations exposed to high natural background radiation. In all cases, no increased cancer risk was associated with any of the studies. On the contrary, some showed a radioprotective effect at higher background levels. Tao *et al.* (*35*) performed a 20 year study of over 125,000 subjects living in an area of high natural background radiation in Yangjiang, China. Risk estimates were negative (i.e., radioprotective effect), although this did not reach statistical significance. Studies from Chernobyl have focused primarily on thyroid cancer where there was a high radiation dose to many adults and children. Apart from the increased incidence of thyroid cancer, the BEIR VII report concluded that "...there is no evidence of an increase in any solid cancer type to date" [p. 228 (*5*)]. Because most environmental studies are descriptive in nature and ecologic in design, they were considered of limited use by the BEIR VII Committee in defining risk of disease in relationship to radiation exposure or dose and largely dismissed from further consideration.

One of the most interesting areas of research on environmental radiation has been radon exposure. A controversial study by Cohen in the late 1990s (*36*, *37*) showed a beneficial effect of low levels of radon. The BEIR VI report (*38*) reviewed these and other ecologic studies and issued a strong judgment: They are not "informative" because of "inherent limitations of the ecologic method" and the latest BEIR VII report does not review or discuss radon exposure. A more recent report by Thompson *et al.* (*39*) describes a rigorous case-control study of lung cancer incidence versus residential radon exposure in Worcester County, Massachusetts, carried out between 1990–1999 with both cases and controls from a single health maintenance organization. Each case was matched individually by age and sex to two controls. Figure 1 shows the adjusted odds ratio of lung cancer as a function of radon concentration in the home. The authors concluded that the possibility of a hormetic effect on lung cancer at low radiation doses cannot be excluded. This would run contrary

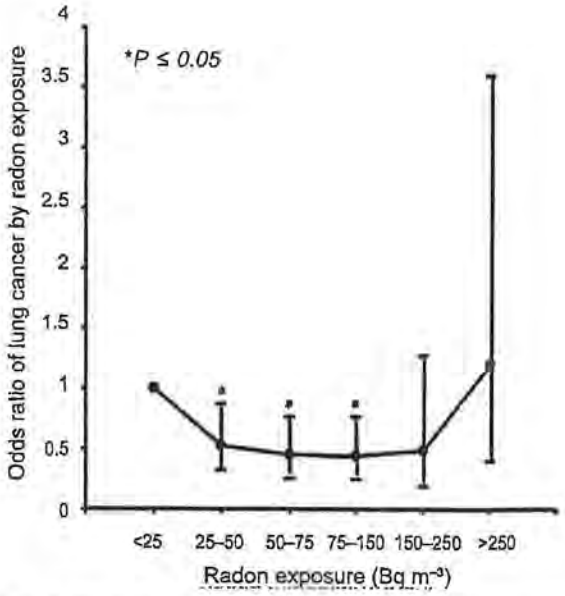

FIG. 1. The odds ratio (95% confidence interval) of lung cancer as a function of radon concentration in the home. Adapted from Table 2, Thompson *et al.* (*39*). Note that the EPA remediation standard of 4pCi/L (i.e., 148 Bq m-3) is in the radio protection (i.e., hormetic) zone.

to the recommendation from the National Academy of Science news report of BEIR VII to consider "living and working on the upper floors of buildings, where there is less radon gas" (*31*).

Occupational Radiation Studies

The largest and most studied group of occupationally exposed workers is that in the nuclear power industry. Most of these workers receive low levels of external radiation (X rays and gamma rays). The most prominent report was from the 15-country collaborative study of over 400,000 nuclear industry workers in 154 facilities (*40*). The study showed a statistically significant increase in the risk of mortality from all cancers excluding leukemia in relationship to radiation exposure, with data from the Canadian sites being the chief driving force behind the worldwide results. Exclusion of the Canadian data resulted in a decrease in the risk of mortality from all cancers including leukemia. This led to a reanalysis of the Canadian data, which showed significant errors in dose reporting at one of their sites. After exclusion of data from that site, reanalysis of the data showed no increased cancer risk among any Canadian nuclear power plant workers and further showed lower rates of all causes of death and cancer mortality for this group than for the general Canadian population (*41*). As the BEIR VII report indicated, in most of the nuclear industry worker studies, rates for all causes and all cancer mortality in the workers were substantially lower than the reference population. The BEIR VII Committee did not attempt to ascertain why, but

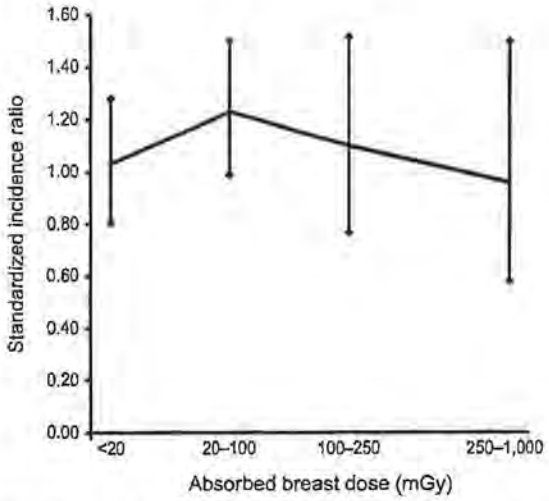

FIG. 2. Standardized incidence ratio for breast cancer as a function of absorbed breast dose. Mean follow-up years was 45. Adapted from Table 4, Lundell *et al.* (*46*).

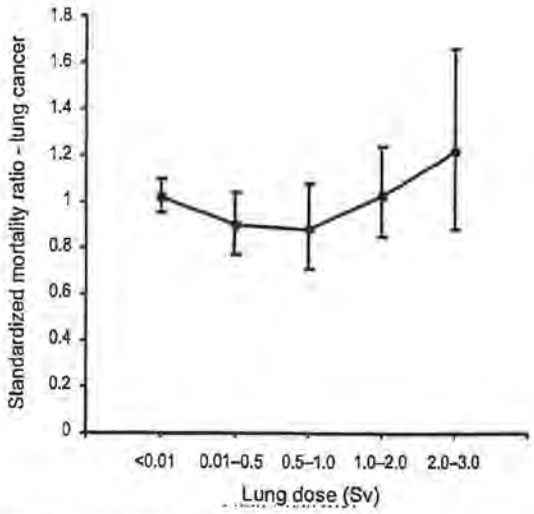

FIG. 3. Standardized mortality ratio for lung cancer as a function of absorbed dose to the lungs. Mean follow-up years was 30. Adapted from Table 3, Howe (*42*).

speculated that it may be due to a "healthy worker effect and unknown differences between nuclear industry workers and the general public". Consequently the BEIR VII Committee concluded that occupational studies were not suitable for the projection of population-based risks and eliminated them from further consideration in its risk estimates.

Medical Radiation Studies

Perhaps one of the most interesting study groups are the medical radiation study groups, since they are comprised of many subjects who are closest in ethnicity, lifestyle and diet to the general U.S. population, and therefore one would expect that cancer risk estimate from these studies would be most appropriate for use in risk estimates. The BEIR VII Committee looked at radiation risk for five types of malignancies (lung cancer, female breast cancer, thyroid cancer, leukemia and stomach cancer). The largest studies were those of Howe and Lundell (*42–46*). Lundell *et al.* (*46*) reported on the risk of breast cancer over a 45 year follow-up period after radiotherapy for skin hemangioma in over 17,000 infants. Howe and McLaughlin (*42, 43*) reported on the incidence of lung and breast cancer over a 40 year follow-up period after fluoroscopy in over 30,000 females aged 10–40 who were treated for tuberculosis. For most cancers observed after high doses, a linear model adequately described the relationship between dose and cancer incidence, however at low doses a very different pattern emerged. As shown here in Fig. 2 from Lundell *et al.* (*46*), no increased risk is observed out to exposures up to 500 mGy mean absorbed dose to the breast. Because of doses to the lungs and other organs, this is equivalent to an effective dose of >100 mSv. Figure 3 shows similar low dose data on the relative risk of lung cancer from the studies of Howe (*42*). In both studies, there is no evidence of increased cancer risk at doses below 100 mSv.

Atomic Bomb Survivor Studies

The Life Span Study (LSS) cohort consists of approximately 120,000 survivors of the atomic bombings in Hiroshima and Nagasaki in 1945. This population has been extensively monitored since 1947 by the Radiation Effects Research Foundation (RERF) and its predecessor, the Atomic Bomb Casualty Commission, and continues to be monitored to this day. Published analysis of data on this cohort forms the basis for almost all risk estimates by the BEIR VII Committee. Unfortunately the BEIR VII report does not present the raw data from the LSS cohort, but instead relies on the risk estimates produced by researchers from the RERF. Indeed many of the published reports from the RERF do not provide the raw data, focusing instead on the various models used for risk estimates. The two most recent publications that provided useful raw data are Preston *et al.* (*47*) with analysis of 40 years of data from 1958–1998 and Ozasa *et al.* (*48*) with analysis of over 50 years of data from 1950–2003. Figure 4 plots the number of solid cancers at each radiation dose taken from Table 4 of Preston *et al.* (*47*) and adjusted to cancers per 100,000 people, with the weighted dose to the colon serving as a surrogate for effective whole-body dose. We have plotted the data on a semi-logarithmic scale to better show the results at low doses. The open circle in Fig. 4 represents the results for inhabitants of Hiroshima and Nagasaki who were not in the cities at the time of the bombings and hence can be assumed to have received none of the blast radiation. It can be seen in Fig. 4 that at doses up to ~100 mGy, no increase in the

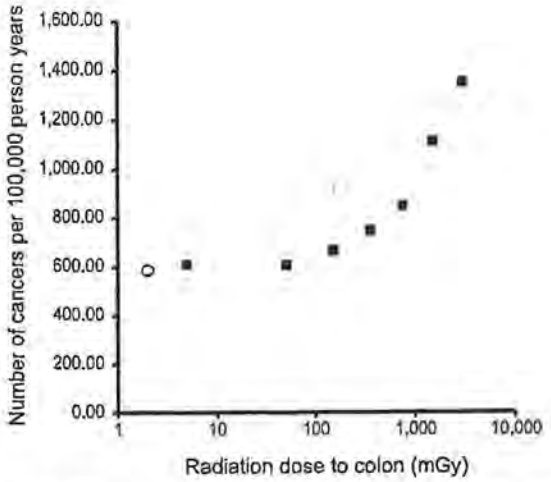

FIG. 4. Number of solid cancers per 100,000 person years as a function of radiation dose to the colon. Adapted from Table 4, Preston *et al.* (*47*). In this study, the weighted dose to the colon serving as a surrogate for effective whole body dose. Data point (○) = cancer incidence in inhabitants of Hiroshima aand Nagasaki who were not in the city at the time of the bombing.

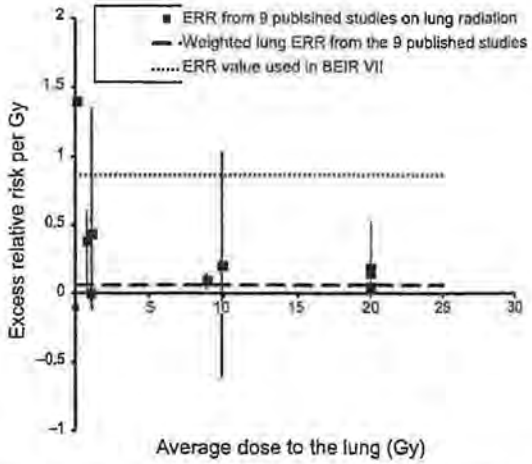

FIG. 5. Distribution of study-specific estimates of ERR/Gy for lung cancer. Dashed line shows weight mean value of ERR for all studies. Dotted line is value of ERR used by BEIR VII. Adapted from Fig. 7-1, BEIR VII (*5*).

number of cancers is observed, and only at doses above that is a significant increase observed. In their analysis, Preston *et al.* (*47*) stated that "based on fitting a series of models with thresholds at the dose cut points...., the best estimate of a threshold was 0.04 Gy with an upper 90% confidence bound of about 0.085 Gy. However this model did not fit significantly better than a linear model". A formal dose-threshold analysis performed on the more recent data reported by Ozasa *et al.* (*48*) indicated that a zero-dose threshold was the best estimate of a threshold dose, However Ozasa *et al.* found that the slope of the dose-response fit was higher at doses below 0.1 Gy than at higher doses, a finding that cannot be explained by the LNT model. Their analysis has been criticized for using a very restrictive model to fit the data (*49*). An analysis by Doss (*50*) using a more flexible model showed that the LSS data does not support a zero dose threshold and concluded that there was too much variability in the data to draw any conclusion as to the existence or absence of a threshold.

RISK MODELS

Even if we ignore the limitations of and arguments against the use of the LNT model and the lack of statistically sound data on the effects at low doses, there still remains the question of how to generate the appropriate risk models and factors to be used in estimating cancer risks at low doses. The BEIR VII Committee had at its disposal two competing risk models: the excess relative risk (ERR) model and the excess absolute risk (EAR) model. The ERR is the rate of disease in an exposed population divided by the rate of disease in an unexposed population, minus 1.0. This is a useful model if the population under investigation is similar to the population on which the model was based, so this would be an excellent model to predict cancer from ionizing radiation in a Japanese population living in wartime conditions. The EAR is the rate of disease in an exposed population minus the rate of disease in an unexposed population. This model is more suitable when there are significant differences (ethnicity, diet, etc.) between the population under investigation and that on which the model was based, and therefore would be better suited when extrapolating risk factors from the Japanese population at the time of the bombings to a U.S. population today. Thus, critical decisions to be made by the BEIR VII Committee included estimation of the values of ERR and EAR for each type of cancer and deciding which model to use and why. These models allow calculation of the risk of cancer at a given time after exposure and their value depends on the age and sex of the subject at the time of exposure. To calculate the lifetime risk of cancer from that exposure, a third model is employed called the lifetime attributable risk (LAR). The LAR is the difference in rate of a condition between the exposed population and an unexposed population. The LAR is an estimate of the probability of developing a premature cancer from radiation exposure over the life of the subject. Thus, it depends on the subject's age at the time of exposure and incorporates several additional factors such as latency period from exposure to first risk of cancer, and the dose and dose rate effectiveness factor, which is discussed in more detail below.

To illustrate the difficulty in calculating the ERR or EAR, consider Fig. 5, which shows values of ERR for lung cancer and is redrawn from Fig. 7-1 in the BEIR VII report [p. 175 (*5*)]. Each point on the graph represents one of nine studies of lung cancer evaluated by the BEIR Committee and

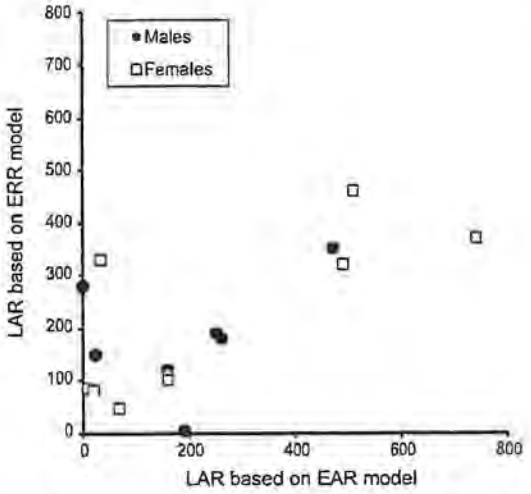

FIG. 6. Relationship between the Lifetime Attributable Risk (LAR) of solid cancer incidence estimated using the EAR and ERR risk models. LAR values are number of cancers per 100,000 persons exposed to 100 mGy. Adapted from Table 12-5A, BEIR VII (*5*).

considered acceptable for use in risk estimation. The graph plots the average dose to patients in each of the nine studies against the estimated value of ERR from each study. Ideally all estimates should be identical and should all lie within one or two standard deviations of each other. The estimates range from ERR = 0.0/Gy (i.e., no risk associated with ionizing radiation) to 1.4/Gy. A weighted mean, based on number of cancers in each study, yielded a risk coefficient of ERR = 0.05/Gy. Demonstrating its strong reliance on the RERF studies, the BEIR VII Committee chose a value of ERR = 0.86/Gy, which is 17 times larger than the weighted mean from all nine medical studies. A similar scenario played out in calculating the ERR for other cancers.

This factor of 17 difference in risk coefficient between the atomic bomb survivor studies and the medical radiation studies illustrates the tremendous uncertainties in estimating the risk factor for a single organ and the dangers in making any risk estimate based on this data. One can now repeat this process and model the data using the EAR model. Given that both models are essentially based on the RERF studies, one would expect reasonable agreement between the models for most cancers. Unfortunately that is not the case. Figure 6 shows the correlation (or lack thereof) between the LAR calculated using the EAR and ERR models based on data presented in Table 12-5A of the BEIR VII report [p. 279 (*5*)]. Each data point represents a different cancer for males and females. For some organs there is good agreement. For example, the LAR for bladder cancer in males is 160 based on the ERR model and 120 based on the EAR model. By comparison, the LAR for stomach cancer in females is 32 based on the ERR model and 330 based on the EAR model, a risk estimate 10 times greater. Given the lack of any significant correlation between the ERR and EAR models, the committee opted to create a final risk model in the form:

Final Risk model = x.ERR + (1 − x).EAR, where the factor x was determined subjectively by the committee. In the BEIR VII report this range of plausible values for LAR for each type of cancer was labeled a "subjective confidence interval" to emphasize its dependence on opinions in addition to direct numerical observation [p. 278 (*5*)]. Furthermore, the BEIR VII Committee went on to state that "because of the various sources of uncertainty it is important to regard specific estimates of LAR with a healthy skepticism, placing more faith in a range of possible values" [p. 278 (*5*)].

One additional factor that is built into the estimation of radiation risk in the BEIR VII report is the dose and dose rate effectiveness factor (DDREF). The DDREF is a factor applied to the LNT model that modifies (reduces) the dose-risk relationship estimated by the model to account for the level of the dose and the rate at which the dose is delivered (i.e., the value for the LAR is divided by the DDREF). The BEIR VII Committee chose a value of 2 for the DDREF. However, use of any value of the DDREF greater than 1 essentially converts the LNT into a linear-quadratic or biphasic model, and provides a means of modifying the linear model without officially abandoning the LNT hypothesis. The BEIR VII Committee did not define low dose and low dose rate, although this is generally accepted to mean cumulative doses less than 200 mGy, which would encompass all medical imaging procedures and background radiation (*51*). Values of the DDREF derived from a wide range of biological end points range from 1–35 (*52*) but are more generally accepted to be in the range from 2–10 (*33*) and suggest the need to have a larger DDREF for adequate and appropriate radiation protection after exposure to low-dose-rate radiation exposures. However, any value of DDREF greater than 5–10 would essentially negate the validity of the LNT and move closer to a threshold model. Since the publication of the BEIR VII report, extensive research in low-dose radiation has shown that the LNT model most likely overestimates the real risk of ionizing radiation at low doses and dose rates (*53*).

AAPM/HPS/UNSCEAR/ICRP/IOMP POLICY STATEMENTS

Many of the limitations of the BEIR VII report are buried deep within this 400-page document. As a consequence, many investigators, clinicians and scientists resort to the summary information presented in the Chapter 12 annexes rather than delve through the main document, and hence fail to appreciate the scientific weakness of the risk estimates generated therein. In particular, Annex 12D of the report provides users with a simple and easy-to-use chart that enables one to calculate the lifetime risk of cancer incidence and mortality for a given amount of radiation and for a

given age of exposure. This chart contains neither confidence intervals nor any message about the myriad of assumptions that went into the creation of these tables. It is partly because of the inappropriate use of these tables that many national and international organizations have issued statements denouncing the practice of multiplying small hypothetical risk estimates by large populations leading to highly speculative claims of the numbers of cancer deaths resulting from medical imaging. In 2011, both the Health Physics Society and the American Association of Physicists in Medicine issued the following position statements (*54*).

"The Health Physics Society recommends against quantitative estimation of health risks below an individual dose of 5 rem (50 mSv) in one year, or a lifetime dose of 10 rem (100 mSv), above that received from natural sources. For doses below 5–10 rem (50–100 mSv) risks of health effects are either too small to be observed or are nonexistent."

The AAPM statement included the following: "Risks of medical imaging at patient doses below 50 mSv for single procedures or 100 mSv for multiple procedures over short time periods are too low to be detectable and may be nonexistent. Predictions of hypothetical cancer incidence and deaths in patient populations exposed to such low doses are highly speculative and should be discouraged. These predictions are harmful because they lead to sensationalistic articles in the public media that cause some patients and parents to refuse medical imaging procedures, placing them at substantial risk by not receiving the clinical benefits of the prescribed procedures."

In addition, most recently UNSCEAR issued the following statement: "In general, increases in the incidence of health effects in populations cannot be attributed reliably to chronic exposure to radiation at levels that are typical of the global average background levels of radiation. This is because of the uncertainties associated with the assessment of risks at low doses, the current absence of radiation-specific biomarkers for health effects and the insufficient statistical power of epidemiological studies. Therefore, the Scientific Committee does not recommend multiplying very low doses by large numbers of individuals to estimate numbers of radiation-induced health effects within a population exposed to incremental doses at levels equivalent to or lower than natural background levels." For reference, UNSCEAR has defined worldwide background as between 2–13 mSv/year (*55*).

LNT MODEL IN PERSPECTIVE

Mechanistic Challenges to LNT-Hit Model

Of significance, is that in the decades following the creation of the LNT single-hit dose response model based on radiation target theory, a series of progressive scientific discoveries have challenged its foundations (*6*). First, it became recognized early on that multiple biological processes could produce linear relationships that did not involve a single-hit process (*56–58*). Second, many adverse effects of ionizing radiation were found to be mediated by hydroxyl radicals that were formed through the hydrolysis of water. Such chemical entities would need to migrate to biological targets and be subject to thermodynamic reaction principles requiring large numbers of molecules to affect a mutational event (*59–61*). Third, numerous cell types were observed to efficiently repair DNA that had been mutated (*62*). Fourth, prior low doses of mutagens, including ionizing radiation and chemicals, were subsequently reported to induce adaptive responses that markedly reduced the mutagenic effects of subsequent more massive exposures (*63, 64*), however, radiation target theory assumed that each dose was additive. Furthermore, hormetic-like biphasic dose responses have been widely reported for numerous end points, including mutations, cell transformation and cancer incidence for ionizing radiation and chemical carcinogens. In fact, many thousands of hormetic studies have been reported in the peer-reviewed literature, challenging not only the generality of the LNT concept but also its application to low-dose settings (*65–67*). Finally, apoptosis was discovered and then viewed within a mutational and cancer framework. It is not uncommon for damaged cells to be selected for destruction, again affecting predictions of the LNT model (*68–70*). In addition to the above, many other dose-dependent adaptive responses have emerged, further challenging the LNT model. For example, large scale toxicology studies often display hormetic dose responses for both ionizing radiation and chemical carcinogens. These studies included the massive FDA-funded mega-mouse study with 24,000 animals (*71*), as well as detailed reinvestigations of the effects of DDT on the rat model upon which regulatory-based risk assessments were made (*72, 73*). Multiple animal studies also revealed that low doses of ionizing radiation can significantly extend the lifespan of various mammalian models (*74, 75*). Reactive oxygen species, initially seen as a vehicle that mediated chemical and ionizing radiation adverse effects, are now viewed as also having critical cellular messaging functions involved in mechanisms by which low doses of ionizing radiation appear to extend life in a number of experimental animal models (*76*).

The LNT single-hit concept has also been challenged by proposals of other cancer risk models such as the multistage model. The LNT model predicted that a single alteration of DNA could initiate the process of carcinogenesis, and that once initiated, this process was irreversible. However, this assumption has been consistently shown to be false (*77*). In one such study Driver *et al.* (*78*) demonstrated that a single administration of the mutagen/carcinogen dimethylnitrosamine (DMN) induced a linear dose response for renal mesenchymal DNA adducts (early cancer process stage), as well as for mesenchymal foci (later cancer process stage), observations consistent with the LNT model. However, the

linear transition to the occurrence of tumor formation was not observed because the foci at the lower doses failed to proceed to the tumor stage, yielding a threshold, rather than a linear dose-response relationship (Fig. 7). Such dose-time response findings are more consistent with the concept of cancer being a multistage process with repair activities occurring at the lower dose.

Regulatory Issues and LNT

An evaluation of all EPA drinking water standards, including those for carcinogens and noncarcinogens, reveals that acceptable levels of exposure are in the range of 10^{12}–10^{20} molecules/liter. The EPA assumes that adult humans ingest two liters per day for a lifetime. This translates into $>10^{24}$ molecules ingested per lifetime without noticeable effect. Since carcinogens at these "acceptable yet numerically massive" doses are expected to have negligible consequences, it reveals an LNT perspective without conceivable theoretical clinical and public health impact.

The adoption of the LNT for generalized use by regulatory agencies such as the EPA was linked with the belief that most human cancer was due to environmental agents. In his historical review of carcinogen regulation, Roy Albert (*79*), chair of the EPA's Carcinogen Assessment Group (CAG), stated that carcinogen risk assessment effort was no less than an attempt by the Federal Government to prevent or greatly reduce cancer in the U.S., with its burden of some half-million deaths per year, by the regulatory control of carcinogens in the general environment.

Despite the fact that most industrialized countries such as the U.S. would be immensely impacted by the social, political and economic implications of the LNT and nagging "reality checks" that challenged the LNT that were ignored by the legislative, regulatory and scientific communities. For example, the number of liver cancers in the U.S. reported in 1980 was about 7,500 per year. Yet, the LNT model estimated that the number of liver cancer cases should have been in excess of 150,000 per year just from normal exposure to only three chemical carcinogens, not including the effects of ethanol, viruses and genetic predispositions (*80*). However, even with this and numerous other such inconsistencies the regulatory community has refused to confront the possibility that their decisions were grossly in error.

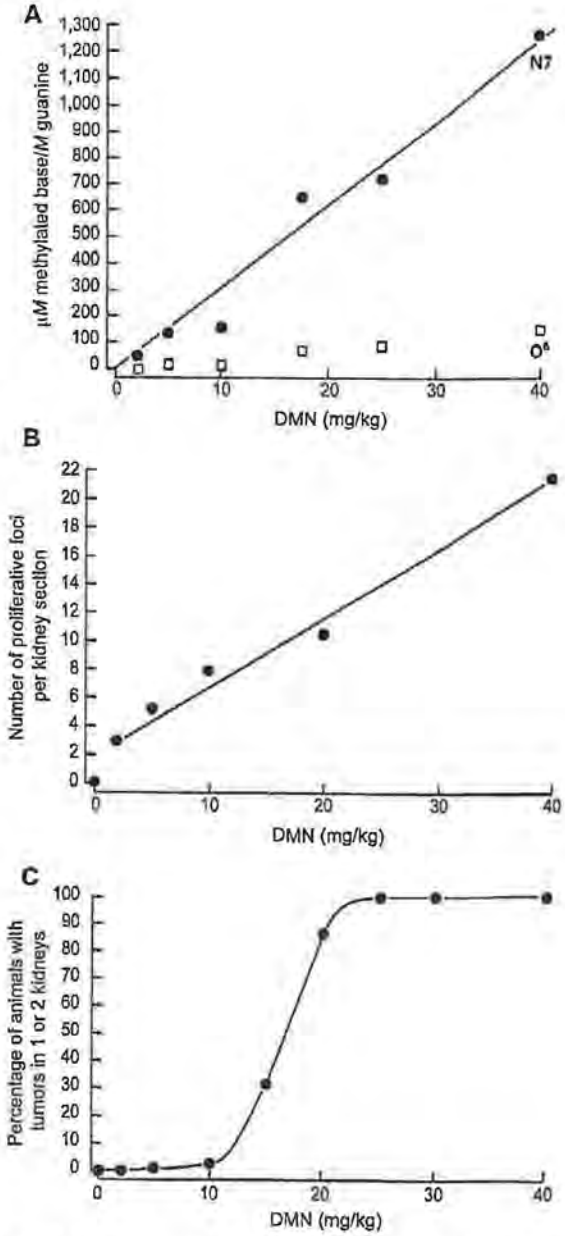

FIG. 7. Dose response for DMN: panel A: renal adducts; panel B: renal foci; panel C: renal tumors. Source: Driver *et al.* (*78*).

Lack of Epidemiological Validation of LNT

Numerous epidemiological studies have been used to support LNT, threshold and hormetic dose responses. However, there are often many limitations with epidemiological studies that preclude obtaining reproducible findings in the low-dose zone, a point that is emphasized in the article "The Limits of Epidemiology" by Taubes and Mann (*81*) and in the published article of Professor John Ioannidis (*82*) at Stanford School of Medicine. Human variability can be extensive, and exposure assessment is often limited and partially inaccurate. In addition, there is the complicating issue of competing causes of death, which can lead to invalid conclusions. Much greater clarity emerges when epidemiological odds ratios exceed two- to threefold. In fact, in the U.S. legal system one cannot usually claim causality until the risks from epidemiological studies have at least doubled (*83*). Yet, in the case of environmental regulation one talks about risks that may be indistinguishable from background or nearly so, as is often seen in epidemiological studies of particulate matter. Thus, as

valuable as human population studies are, there is little likelihood that epidemiological studies have the capacity to validate and/or test LNT predictions in the low-dose/risk zone. To better understand the nature of the dose response in the low-dose zone it is necessary to use biological models with low variability, high reproducibility and where mechanistic follow-up is practical. This is why the emphasis on assessing the occurrence of hormetic dose responses in the Hormesis Database involves cell model and whole animal studies (*84, 85*).

Individual Versus Population-Based Thresholds

It has been argued that while there may be thresholds for individuals there are no thresholds for populations, since humans display such widespread genetic, social, behavioral and cultural heterogenicity. While there can be significant inter-individual variability in response to toxic substances suggesting support for a population-based LNT model perspective, this argument fails to be useful in the LNT debate. Since people are typically exposed to greater than 10^{24} molecules of individual regulated carcinogens at *de minimus* risk levels ($<10^{-6}$ lifetime cancer risk), even adding a 100–1,000 greater response sensitivity in a group at high risk would mean that such dose levels are still without notable effect (*86*). That is, even populations have thresholds.

CONCLUSION

We contend that the decision to accept the LNT model was based on a flawed scientific foundation. It was promoted through a series of highly biased representations of the data by leading radiation geneticists in the 1940s and 1950s. These geneticists convinced their colleagues on key committees such as the United States National Academy of Sciences BEAR I Genetics Panel in 1956 to switch from the threshold to the LNT for genomic risk assessment.

The main source of data for the BEIR VII risk estimates was obtained from the survivors of the Japanese A-bomb explosions, a population greatly different from the U.S. population that was exposed to radiation conditions greatly different from those of medical imaging. Even so, data from the Japanese studies frequently reveal a threshold dose for increased cancers in the irradiated populations. Collectively, the uncertainties in the derivation of the BEIR VII risk estimates, and the intrinsic speculative nature of the risk estimates themselves, cause predictions of cancers and cancer deaths to be more hypothetical than real in populations exposed to medical imaging. Several scientific organizations, including the Health Physics Society, American Association of Physicists in Medicine, the International Organization of Medical Physicists, the United Nations Scientific Committee on the Effects of Atomic Radiation and the International Commission on Radiological Protection, have warned against making such predictions because of their speculative nature, supporting the conclusion that the risk projection model recommended in BEIR VII report should not be used for estimating cancer risks from low doses of radiation.

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REFERENCES

1. Ionizing radiation exposure of the population of the United States. NCRP Report No. 160. Bethesda: National Council on Radiation Protection and Measurements; 2009.
2. Brenner DJ, Elliston CD. Estimated radiation risks potentially associated with full-body CT screening. Radiology 2004; 232:225–9.
3. Smith-Bindman R, Lipson J, Marcus R, Kim KP, Mahesh M, Gould R, et al. Radiation dose associated with common computed tomography examinations and the associated lifetime attributable risk of cancer. Arch Intern Med 2009; 169:2078–86.
4. Berrington de González A, Mahesh M, Kim KP, Bhargavan M, Lewis R, Mettler F, et al. Projected cancer risks from computed tomographic scans performed in the United States in 2007. Arch Intern Med 2009; 169:2071–7.
5. NCR, Health risks from exposures to low levels of ionizing radiation: BEIR VII Phase 2. National Research Council, Washington DC: National Academy Press; 2006.
6. Tubiana M, Aurengo A, Averbeck D, Bonnin A, LeGuen B, Masse R. Dose-effect relationships and estimation of the carcinogenic effect of low doses of ionizing radiation. Joint Report of the Academie des Sciences, Academie Nationale de Medecine: 2005.
7. Muller HJ. Artificial transmutation of the gene. Science 1927; 66:84–7.
8. Olson AR, Lewis GN. Natural reactivity and the origin of species. Nature 1928; 121:673–4.
9. Muller HJ, Mott-Smith LM. The frequency of translocations produced by x-rays in Drosophila. Genetics 1930; 15:283–331.
10. Giles N. Spontaneous chromosome aberrations in Tradescantia. Genetics 1940; 25:69–87.
11. Calabrese EJ. Origin of the linearity no threshold (LNT) dose-response concept. Arch Toxicol 2013; 87:1621–33.
12. Calabrese EJ. How the U.S. National Academy of Sciences misled the world community on cancer risk assessment: new findings challenge historical foundations of the linear dose response. Arch Toxicol 2013; 87:2063–81.
13. Timofeeff-Ressovsky NW, Zimmer KG, Delbruck M. Uber die Natur der Genmutation und der Genstruktur. Nachrichten von der Gesellschaft der Wissenschaften zu Gottingen: Mathematische-Physikalische Klass, Fachgruppe VI. Biologie 1935; 1:189–245.
14. Calabrese EJ. The road to linearity: why linearity at low doses became the basis for carcinogen risk assessment. Arch Toxicol 2009; 83:203–25.
15. Calabrese EJ. Toxicology rewrites its history and rethinks its future: giving equal focus to both harmful and beneficial effects. Environ Toxicol Chem 2011; 30:2658–73.
16. NAS/National Research Council. The biological effects of atomic radiation. A report to the public. Washington DC; 1956.

17. Crow JF. Quarreling geneticists and a diplomat. Genetics 1995; 140:421–6.
18. Calabrese EJ. Key studies to support cancer risk assessment questioned. Environ Mol Mut 2011; 52:595–606.
19. Calabrese EJ. Muller's Nobel Prize lecture: when ideology prevailed over science. Toxicol Sci 2012; 126:1–4.
20. Uphoff DE, Stern C. The genetic effects of low intensity irradiation. Science 1949; 109:609–10.
21. Caspari E, Stern C. The influence of chronic irradiation with gamma rays at low dosages on the mutation rate in Drosophila melanogaster. Genetics 1948; 33:75–95.
22. Spencer WP, Stern C. Experiments to test the validity of the linear R-dose/mutation at low dosage. Genetics 1948; 33:43–74.
23. Calabrese EJ. Response to letter of Ralph J. Cicerone and Kevin Crowley regarding "How the U.S. National Academy of Sciences misled the world community on cancer risk assessment: New findings challenge historical foundations of the linear dose response." Arch Toxicol 2014; 88:173–7.
24. Kesavan PC. Linear, no threshold model in low-dose radiobiology-ideology versus science. Curr Sci 2014; 107:46–53.
25. Oliver CP. The effect of varying the duration of X-ray treatment upon the frequency of mutation. Science 1930: 71:44–6.
26. Hanson FB, Heys F. Radium and lethal mutations in Drosophila; further evidence of the proportionality rule from the effects of equivalent doses differently applied. Am Nat 1932; 66:335–45.
27. Hanson FB, Heys F. An analysis of the effect of the different rays of radium in producing lethal mutations in Drosophila. Am Nat 1929; 63:201–13.
28. Weinstein A. The production of mutations and rearrangements of genes by X-rays. Science 1928; LXVII:376–7.
29. Stadler LJ. Some genetic effects of X-rays in plants. J Hered 1930; 21:3–19.
30. Serebrowsky AS, Dubinin NP. X-ray experiments with Drosophila. J Hered 1930; 21:259–65.
31. National Academies News Report. Low levels of ionizing radiation may cause harm. June 29, 2005. (http://www8.nationalacademies.org/onpinews/newsitem.aspx?RecordID=11340)
32. NRC, The effects on populations of exposure to low levels of ionizing radiation, BEIR III. National Research Council, Washington, DC: National Academy Press; 1980.
33. NRC, Health Effects of Exposure to Low Levels of ionizing radiation, BEIR V. National Research Council, Washington, DC: National Academy Press; 1990.
34. Jablon S, Hrubec Z, Boice JD. Cancer in populations living near nuclear facilities. A survey of mortality nationwide and incidence in two states. JAMA 1991; 265:1403–8
35. Tao Z, Cha Y, Sun Q. Cancer mortality in high background radiation area of Yangjiang, China, 1979–1995. Zhonghua Yi Xue Za Zhi. 1999; 79:487–92.
36. Cohen BL. Test of the linear-no threshold theory of radiation carcinogenesis for inhaled radon decay products. Health Phys 1995; 68:157–74.
37. Cohen BL. Lung cancer rate vs. mean radon level in U.S. counties of various characteristics. Health Phys 1997; 72:114–9.
38. NRC, Health effects of exposure to radon, BEIR VI. National Research Council, Washington, DC: National Academy Press; 1999.
39. Thompson RE, Nelson DF, Popkin JH, Popkin Z. Case-control study of lung cancer risk from residential radon exposure in Worcester County, Massachusetts. Health Phys 2008; 94:228–41.
40. Cardis E, Vrijheid M, Blettner M, Gilbert E, Hakama M, Hill C, et al. The 15-Country collaborative study of cancer risk among radiation workers in the nuclear industry: estimates of radiation-related cancer risks. Radiat Res 2007; 167:396–416.
41. CNSC, Verifying Canadian nuclear energy worker radiation risk: a reanalysis of cancer mortality in Canadian nuclear energy workers (1957–1994): Summary report. Minister of Public Works and Government Services Canada. Catalogue number CC172-65/2011E-PDF. ISBN 978-1-100-17760-1. Canadian Nuclear Safety Commission; 2011.
42. Howe GR. Lung cancer mortality between 1950 and 1987 after exposure to fractionated moderate-dose-rate ionizing radiation in the Canadian fluoroscopy cohort study and a comparison with lung cancer mortality in the atomic bomb survivors study. Radiat Res 1995; 142:295–304.
43. Howe GR, McLaughlin J. Breast cancer mortality between 1950 and 1987 after exposure to fractionated moderate-dose-rate ionizing radiation in the Canadian fluoroscopy cohort study and a comparison with breast cancer mortality in the atomic bomb survivors study. Radiat Res 1996; 145:694–707.
44. Lundell M, Mattsson A, Hakulinen T, Holm LE. Breast cancer after radiotherapy for skin hemangioma in infancy. Radiat Res 1996; 145:225–30.
45. Lundell M, Holm LE. Mortality from leukemia after irradiation in infancy for skin hemangioma. Radiat Res 1996; 145:595–601.
46. Lundell M, Mattsson A, Karlsson P, Holmberg E, Gustafsson A, Holm LE. Breast cancer risk after radiotherapy in infancy: a pooled analysis of two Swedish cohorts of 17,202 infants. Radiat Res 1999; 151:626–32.
47. Preston DL, Ron E, Tokuoka S, Funamotm S, Nishi N, Soda M, et al. Solid cancer incidence in atomic bomb survivors: 1958–1998. Radiat Res 2007; 168:1–64.
48. Ozasa K, Shimizu Y, Suyama A, Kasagi F, Soda M, Grant EJ, et al. Studies of the mortality of atomic bomb survivors, Report 14, 1950–2003: an overview of cancer and noncancer diseases. Radiat Res 2012; 177:229–43.
49. Doss M, Egleston BL, Litwin S. Comments on "Studies of the mortality of atomic bomb survivors, report 14, 1950–2003: an overview of cancer and noncancer diseases" (Radiat Res 177, 229–243, 2012). Radiat Res 2012; 178:244–5.
50. Doss M. Linear no-threshold model vs. radiation hormesis. Dose Response 2013; 11:480–97.
51. UNSCEAR, Sources and effects of ionizing radiation. New York: United Nations; 1993.
52. Dauer LT, Brooks AL, Hoel DG, Morgan WF, Stram D, Tran P. Review and evaluation of updated research on the health effects associated with low-dose ionizing radiation. Radiat Prot Dosimet 2010; 140:103–36.
53. Brooks AL, Dauer LT. Advances in radiation biology: effect on nuclear medicine. Semin Nucl Med 2014; 44:179–86.
54. Hendee WR, O'Connor MK. Radiation risks of medical imaging: separating fact from fantasy. Radiology 2012; 264:312–21.
55. UNSCEAR, Chapter II, Section 1(f) Attributing health effects to radiation exposure and inferring risks. Report of the United Nations Scientific Committee on the effects of atomic radiation - Fifty-ninth session, 21–25 May 2012, Supplement No. 46. New York: United Nations; 2012.
56. Zimmer KG. Ergebnisse und Grenzen der treffertheoretischen Deutung von strahlenbiologischen Dosis-Effekt-Kurven. Biol Zentral 1941; 63:78.
57. Haas FI, Clark JB, Wyss O, Stone WS. Mutations and mutagenic agents in bacteria. Am Nat 1950; 84:261–74.
58. Kimball RF. Genetic effects of radiation. Ann Rev Nucl Sci 1952; 1:479–94.
59. Collinson E, Dainton FS, Smith DR, Tazuke S. Evidence for unit negative charge on hydrogen atom formed by action of ionising radiation on aqueous systems. Proc Chem Soc 1962; 140–4.
60. Czapski G, Schwarz HA. The nature of the reducing radical in water radiolysis. J Phys Chem 1962; 66:471–9.
61. Weiss J. Radiochemistry of aqueous solutions. Nature 1944; 153:748–50.

62. Hanawalt PC. Evolution of concepts in DNA repair. Environ Mol Mut 1994; 23(suppl 24):78–85.

63. Samson L, Cairns J. New pathway for DNA-repair in Escherichia coli. Nature 1977; 267:281–3.

64. Olivieri G, Bodycote J, Wolff S. Adaptive response of human lymphocytes to low concentrations of radioactive thymidine. Science 1984; 223:594–7.

65. Calabrese EJ, Baldwin LA. Toxicology rethinks its central belief - hormesis demands a reappraisal of the way risks are assessed. Nature 2003; 421:691–2.

66. Calabrese EJ. Hormesis: why it is important to toxicology and toxicologists. Environ Toxicol Chem 2008; 27:1451–74.

67. Sanders CL. Radiation hormesis and the linear-no-threshold assumption. Heidelberg, Germany: Springer-Verlag; 2010.

68. Scott BR. Stochastic thresholds: a novel explanation of nonlinear dose-response relationships for stochastic radiobiological effects. Dose Response 2006; 3:547–67.

69. Scott BR. Low-dose radiation-induced protective process and implications for risk assessment, cancer prevention, and cancer therapy. Dose Response 2007; 5:131–49.

70. Scott BR. It's time for a new low-dose-radiation risk assessment paradigm one that acknowledges hormesis. Dose Response 2008; 6:333–51.

71. Bruce RD, Carlton WW, Ferber KH, Hughes DH, Quast JF, Salsburg DS, et al. Reexamination of the ED01 study why the society of toxicology became involved. Fund Appl Toxicol 1981; 1:26–128.

72. Fukushima S, Kinoshita A, Puatanachokchai R, Kushida M, Wanibuchi H, Morimura K. Hormesis and dose-response-mediated mechanisms in carcinogenesis: evidence for a threshold in carcinogenicity of non-genotoxic carcinogens. Carcinogenesis 2005; 26:1835–45.

73. Sukata T, Uwagawa S, Ozaki K, Ogawa M, Nishikawa T, Iwai S, et al. Detailed low-dose study of 1,1--bis(p-chlorophenyl)-2,2,2-trichloroethane carcinogenesis suggests the possibility of a hormetic effect. Int J Cancer 2002; 99:112–8.

74. Ina Y, Sakai K. Further study of prolongation of life span associated with immunological modification by chronic low-dose-rate irradiation in MRL-1pr/1pr mice: effects of whole-life irradiation. Radiat Res 2005; 163:418–23.

75. Ina Y, Tanooka H, Yamada T, Sakai K. Suppression of thymic lymphoma induction by lifelong low-dose-rate irradiation accompanied by immune activation in C57BL/6 mice. Radiat Res 2005; 63:153–8.

76. Ludovico P, Burhans WC. Reactive oxygen species, ageing and the hormesis police. FEMS yeast research 2013; 14:33–9.

77. Williams GM, Iatropoulos MJ, Jeffrey AM. Thresholds for DNA-reactive (genotoxic) organic carcinogens. Toxicol Pathol 2005; 18:69–77.

78. Driver HE, White IH, Butler WH. Dose-response relationships in chemical carcinogenesis: renal mesenchymal tumours induced in the rat by single dose dimethylnitrosamine. Br J Exp Path 1987; 68:133–43.

79. Albert RE. Carcinogen risk assessment in the U.S. environmental protection agency. Crit Rev Toxicol 1994; 24:75–85.

80. Calabrese EJ. Principles of animal extrapolation. New York: John Wiley and Sons, Inc; 1983.

81. Taubes G, Mann CC. Epidemiology faces its limits. Science 1995; 269:164–9.

82. Ioannidis JPA. Why most published research findings are false. PLoS Med 2005; 2:e124.

83. Carruth RS, Goldstein BD. Relative risk greater than two in proof of causation in toxic tort litigation. Jurimetrics 2001; 41:195–209.

84. Calabrese EJ, Blain R. The occurrence of hormetic dose responses in the toxicological literature, the hormesis database: an overview. Toxicol Appl Pharm 2005; 202:289–301.

85. Calabrese EJ, Blain R. The hormesis database: the occurrence of hormetic dose responses in the toxicological literature. Reg Toxicol Pharm 2011; 61:73–81.

86. Calabrese EJ. The dose-response: A fundamental concept in toxicology. In: AW Hayes, Editor. Principles and methods of toxicology, 6th ed. Boca Raton FL: CRC Press; 2014.