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To: Sierra Club Atlantic Chapter

Subject: Hakes FSEIS does not rebut the evidence presented by Sierra Club

Date: February 21, 2019

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Introduction

This memorandum addresses the points made regarding radioactivity issues in the responses to public comments by both the NYS Department of Environmental Conservation (DEC) and the Town of Campbell in the Final Supplemental Environmental Impact Statement for the Hakes C&D Disposal - Landfill Expansion Project, dated December 5, 2018 (the "FSEIS"). The responses of the Town of Campbell include a report prepared for the town by Theodore E. Rahon, Ph.D., Certified Health Physicist, CoPhysics Corporation, titled *Report: A Review of Drill Cuttings Disposal at the Hakes C&D Landfill and Response to Public Comment*, dated May 16, 2018, and attached to the Town of Campbell response to comments, Appendix 5 to the FSEIS (the "CoPhysics Report"). Responses from both DEC and CoPhysics are addressed here. The Town of Campbell has not provided independent responses on radioactivity issues but, instead, has referred to the DEC and CoPhysics responses.

In particular, this memorandum addresses whether DEC and CoPhysics satisfactorily respond to the points made in my affidavit of January 18, 2018, my presentation of February 10, 2018, and the comments on the Draft Supplemental Environmental Impact Statement ("DSEIS") that the Sierra Club Atlantic Chapter submitted to DEC and the Town of Campbell on March 19, 2018 (the "Sierra Club comment letter"). My affidavit and presentation were attached as exhibits to the Sierra Club comment letter.

I. The evidence shows that Hakes Landfill contains radioactive material, and that this radioactive material is poorly characterized

The evidence of radioactive material in the landfill comes from the landfill's leachate test results which show intermittently high levels of certain radionuclides (known as "radium progeny") that are produced by the radioactive decay of radium. The overarching issue is whether the leachate test results combined with the unreliability of the entrance monitors indicate that the Hakes landfill contains unacknowledged radioactive waste (particularly radium) that substantially exceeds the landfill's regulatory limit of 25 picocuries per gram (pCi/g). If so, the long-term health issues from such disposal need to be addressed.

Evidence that the radioactive material in the landfill is poorly characterized includes a major discrepancy between a) the radium levels detected by the landfill's entrance monitor which my January 18, 2018 affidavit shows is unreliable and b) the high levels of radium progeny in the leachate and landfill gas. Additional evidence that the radioactive material in the landfill is poorly characterized is provided by the fact that the levels of radium progeny in leachate are *intermittently* very high, varying by orders of magnitude from one test to another, for reasons that are neither explained nor understood. The issues that must be resolved are:

- why the radon levels are intermittently very high,
- the radium source for the intermittently high radon levels, and
- the effects on human health from the presence and dispersal of intermittently high radon levels, and also from the radium itself.

DEC acknowledges in the FSEIS that *there is a major discrepancy between the radium that DEC and the landfill operator can account for and the high levels of radium progeny in the leachate and landfill gas*. In responding to a comment on the high levels of radium progeny in the leachate and landfill gas, DEC has said:

> Considering the limited amount of drill cuttings that have been accepted to date at the landfill, and the minimal values of Ra-226 present in those cuttings, there is no plausible manner in which such radon values in air or leachate can be caused by the drill cuttings present.

FSEIS at 26.

This is exactly the point at issue. DEC has attempted to dismiss the intermittently high radon levels by referencing the landfill's regulatory limit of 25 pCi/g and the ability of the landfill's

entrance monitors to detect waste loads above the regulatory limit. DEC also asserts that there are "minimal values" of Radium-226 in the drilling wastes accepted for disposal. On the basis of these three points, DEC claims the test results showing high levels of radium progeny in the leachate and landfill gas must be either wrong or not attributable to the drilling wastes. However, the available scientific evidence shows that the test results are *not* wrong and not readily attributable to any other source than the wastes accepted from drilling operations, as explained in detail in my affidavit of January 18, 2018, my presentation of February 10, 2018, the Sierra Club comment letter dated March 19, 2018, and this memo. Additional testing and modeling must be conducted to adequately rebut/resolve the leachate test results.

A major component of DEC's argument is that the gamma-detector entrance monitors used at Hakes will reliably detect radioactive materials coming into the landfill. To the contrary, as explained in my affidavit, these entrance monitors cannot reliably detect and prevent entry of waste loads carrying more than 25 pCi/g radium due to poorly constrained disequilibrium between radium and radon.

DEC argues unsuccessfully against the landfill's leachate tests results and what they show. Levels of radium progeny Lead-214, Bismuth-214, and Radon-222 in landfill leachate are intermittently very high (with radon ranging up to about 270,000 picocuries per liter [pCi/L]), as known from strong supporting evidence and lack of contrary evidence. Recent Lead-210 tests are said to contradict the intermittently high results but are in fact irrelevant; they fall in the category of "lack of contrary evidence." The strong supporting evidence includes valid and internally consistent results from gamma spectroscopy/spectrometry leachate testing, combined with recognized decay-correction procedures, with error bounds for such test results and procedures being well-established. These well-supported results show intermittently high radon levels in landfill gas that may range up to about 1.05 million pCi/L or more. Such intermittently high radon levels are likely to have onsite and offsite effects, exposing landfill workers and downwind residents to some level of radiological dose and risk. Additional testing and modeling are needed to a) characterize and quantify such dose and risk, b) identify and characterize the flow pathways for radon and the extreme variations in test results for its progeny, and c) locate, characterize, and quantify the radium that is generating the intermittently high levels of radon and other progeny. As indicated below, the intermittently high results are problematic regardless of whether the radon is from naturally occurring onsite radium or from radium-bearing waste brought into the landfill.

A. Summary of evidence previously presented by Sierra Club of intermittently high levels of radioactivity in landfill's leachate test results[1]

The annual reports of the Hakes C&D landfill in the Town of Campbell, Steuben County, NY, show that the landfill, which began operation in 1989, has accepted certain drilling-related wastes from Pennsylvania oil & gas operations since about 2010. As explained in documents

[1] See also section IV of this memo for a comment-by-comment review of the Sierra Club comment letter.

such as my January 18, 2018 affidavit on behalf of Sierra Club, *a major concern is that a substantial amount of the drilling-related waste in Hakes landfill exceeds the 25 pCi/g regulatory limit*. Construction and demolition debris (C&D) landfills in New York are not allowed to accept drilling-related waste that contains more than 25 pCi/g radium.

Hakes has been required to submit leachate samples for semiannual testing of radium and certain radium progeny, including Lead-214 and Bismuth-214, with results reported in pCi/L. Test results from *most* of the leachate samples have shown relatively low levels of these radionuclides, typically less than about 50 pCi/L for both Lead-214 and Bismuth-214 and less than about 4 pCi/L for Radium-226.

If all of the Hakes leachate test results were similarly low, there would be no reason to suspect that a substantial amount of the radium-bearing waste brought into the landfill exceeds the 25 pCi/g regulatory limit. In other words, there would be little or no scientific basis for such a concern if the leachate test results *always* showed less than about 50 pCi/L for both Lead-214 and Bismuth-214.

In fact, the Hakes leachate test results for Lead-214 and Bismuth-214 are *intermittently very high*, ranging far beyond 50 pCi/L to about 6000 pCi/L. These strange and unexplained test results create a justified concern that substantial amounts of the radium-bearing waste brought into the landfill have exceeded the 25 pCi/g regulatory limit. The scientific basis for this concern has been set forth in my affidavit of January 18, 2018, my presentation of February 10, 2018, and the Sierra Club comment letter dated March 19, 2018.

The same sources, as discussed herein, show two further implications of such leachate test results ranging up to ~6000 pCi/L. First, the evidence shows that intermittently high levels of radon have been present in Hakes leachate, ranging up to ~270,000 pCi/L at the time the leachate samples were collected. Second, it is likely that continually high or intermittently high levels of radon are/have been present in landfill gas at levels ranging up to about 1 million pCi/L.

The following figures from my January 18, 2018 affidavit show the intermittently high levels of Lead-214 and Bismuth-214 in the leachate, ranging up to ~6000 pCi/L, and the substantially lower levels of Radium-226 in the leachate, as reported in the semiannual test results for these three radionuclides.[2] Similar results, ranging up to ~1000 pCi/L, are shown by the data from the Chemung County landfill leachate tests. These results are included here because they illustrate that another landfill that has taken high levels of drill cuttings and other gas drilling wastes also manifests intermittently high levels of Lead-214 and Bismuth-214 in leachate.

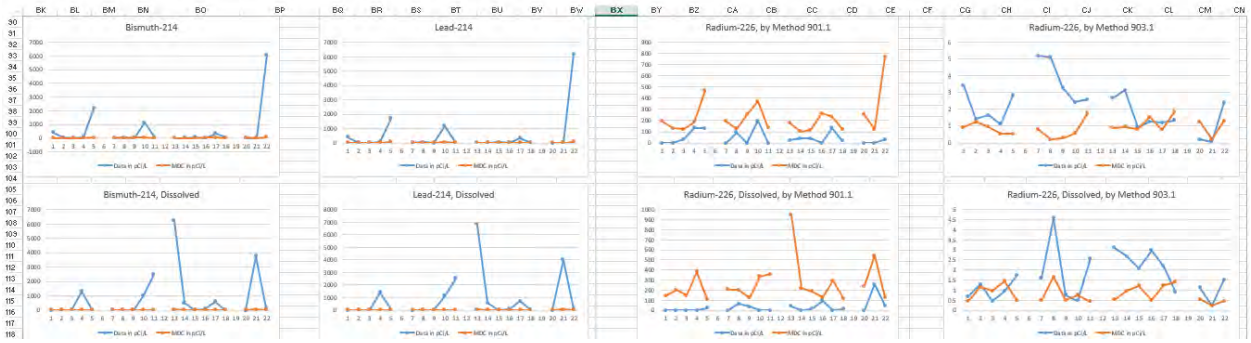
Results from the Hakes and Chemung County leachate test reports are plotted below, where the horizontal axis on each graph is time, and the graphs show four different time trends. The blue

[2] Note that Radon-222 has not been routinely tested in these semiannual samples, but its concentration in a given sample can be determined from its parent-progeny relationships to Lead-214 and Bismuth-214. Nor was Lead-210 routinely tested prior to 2018, as discussed below.

lines show the reported test results, while the orange lines show the detection limit (MDC) for each test. See Exhibits S-Z of my January 18, 2018 affidavit for these graphs in larger format.

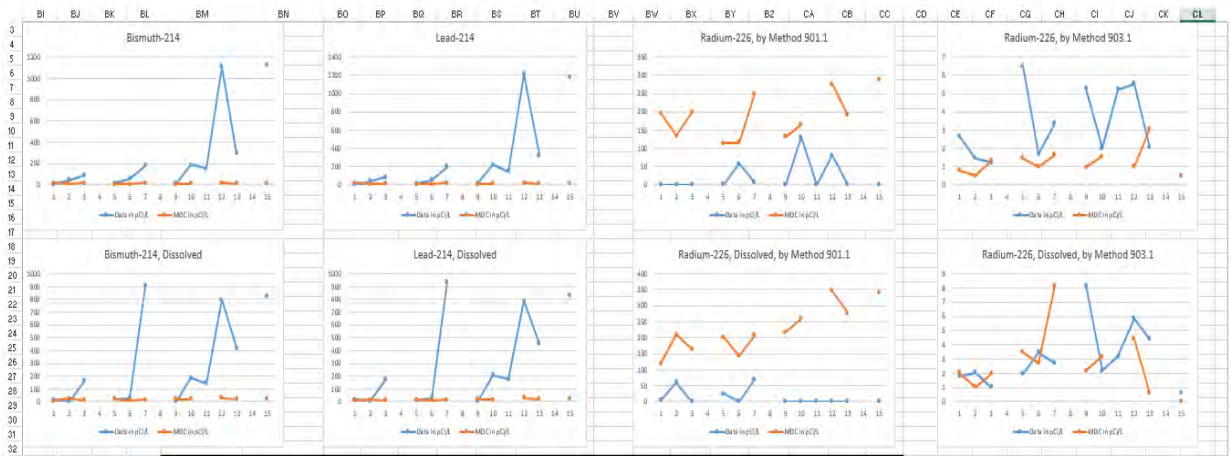
For Hakes Landfill:

- 1-5 are the 2015-2017 time trend for Cell 3 Leachate
- 7-11 are the 2015-2017 time trend for Cell 4 Leachate
- 13-18 are the 2014-2017 time trend for Cell 5 Leachate
- 20-22 are the 2016-2017 time trend for Cell 8B Leachate



For Chemung County Landfill:

- 1-3 are the 2015-2017 time trend for Leachate Pond (Combined Leachate)
- 5-7 are the 2015-2017 time trend for Cells I through III Primary Leachate
- 9-13 are the 2015-2017 time trend for Cell IV Primary Leachate
- 15 is the single data point for the 2017 measurement of Cell V Primary Leachate.



In summary, the above graphs show that the test results (blue lines) for Bismuth-214 and Lead-214 are intermittently very high, ranging up to about 6000 pCi/L in Hakes leachate and 1000 pCi/L in Chemung leachate, while the test results (blue lines) for radium in Hakes and Chemung leachate remain much lower.

B. Significance of this evidence

The evidence of intermittently high levels of radon in the landfill's leachate test results is significant because of two unresolved issues involving radon gas. One issue is the *effects* of radon in landfill gas, particularly human health effects, which have not been addressed. The other issue is the *source* of this radon. The source must be radium, but the unaddressed/unresolved issue is the quantity, origin, and location of radium within the landfill.

1. EFFECTS OF RADON: Part of the significance of the evidence is the likelihood of continually high or intermittently high radon in landfill gas, ranging up to ~1 million pCi/L, escaping into the atmosphere to an unknown extent and exposing humans and the environment to currently unmeasured radiological dose and thus risk.

2. SOURCE OF RADON: Part of the significance of the evidence is that the amount and location of *radium* capable of producing intermittently high radon levels within the landfill remain unknown. The existing evidence cannot resolve the question of whether such radium is mostly:

a) naturally occurring onsite radium (but if so, why are radon levels so intermittently high, and how do such large quantities of radon pass through the landfill liner into the leachate?), or

b) offsite radium brought onsite in radium-bearing wastes such as drill cuttings that *do not* exceed the 25 pCi/g limit (but if so, why are radon levels so intermittently high?), or

c) offsite radium brought onsite in radium-bearing wastes that *exceed* the 25 pCi/g limit.

Note that the effects and source may be interrelated. If the source is (c), offsite radium brought onsite in radium-bearing wastes that exceed 25 pCi/g, then *long-term health effects from such radium disposal* become increasingly significant.

II. DEC and CoPhysics do not rebut the evidence presented by Sierra Club

This section provides a detailed point-by-point review of the evidence and lack of substantive and credible rebuttal. See also section IV below for a comment-by-comment overview of the Sierra Club comment letter.

A. Recent Lead-210 test results do not rebut the earlier test results

The recent Lead-210 test results do not rebut the earlier test results showing intermittently high levels of radioactive material in the landfill. The recent Lead-210 tests cited by CoPhysics were

performed on leachate samples in which Lead-214, Bismuth-214, and radon were *not* intermittently high. Such results cannot rebut earlier test results from leachate samples that were not tested for Lead-210 but showed high Lead-214, Bismuth-214, and radon.

This is one of the instances where CoPhysics and DEC have set up flawed arguments by which they seek to dismiss any concerns about the high radionuclide levels. In this instance the flaw is a failure to distinguish between *continuously high* and *intermittently high* levels of radium progeny such as Lead-214, Bismuth-214, and Radon-222. The CoPhysics argument relies on recent test data showing relatively low levels of Lead-210, Lead-214, and Bismuth-214. Based on the low test results for Lead-210, CoPhysics concludes that high levels of radium progeny such as Lead-214, Bismuth-214, and Radon-222, *if continuously high*, are impossible. Such a conclusion is irrelevant and invalid for the intermittently high levels that have been documented at both Hakes and Chemung landfills.

It is unfortunate that Lead-210 testing was not done on the earlier samples that contained high levels of Lead-214 and Bismuth-214. Such testing would have resolved most of the questions at issue here. The Lead-210 level in a given sample is necessarily correlated with the Lead-214 and Bismuth-214 levels through the parent-progeny relationships among these radionuclides.

B. The landfill's own tests used a valid method to measure radioactivity in leachate samples that showed high results

EPA Method 901.1 is valid. Questions in the FSEIS about its validity are improper and misleading. In questioning the method, DEC and CoPhysics cast unfounded doubt on the validity of a well-known gamma spectroscopy/spectrometry test method that has been routinely used for radiological analysis of the leachate samples collected semiannually at Hakes and other landfills.

DEC and CoPhysics claim that gamma spectroscopy/spectrometry results obtained with EPA Method 901.1 are invalid or untrustworthy because the uncertainty associated with this method is too high. I have researched the documents summarized in Exhibit A in an effort to find any support for these claims. DEC's recent revision of 6 NYCRR Parts 360-363 provides a few poorly explained clues and noticeable gaps (see Exhibit A), but nothing resembling a rational basis for distrusting Method 901.1 due to its alleged uncertainty.

DEC's and CoPhysics' complaints about "uncertainty" boil down to a simple fact that is well-known to testing labs and those who submit samples and review the results. Quite simply, when the activity (radioactivity) of a given radionuclide in a given sample is *higher* than the Minimum Detectable Concentration (MDC), then Method 901.1 is reliable and useful. When the activity of a given radionuclide in a given sample is *below* the Minimum Detectable Concentration, then Method 901.1 does not provide reliable or useful results because, in effect, "noise" overwhelms the signal. This is simple common sense that should not be distorted into a broad suspicion about the "uncertainty" of Method 901.1.

Note that "uncertainty" in this context doesn't have its everyday meaning of generalized doubt or unpredictability. "Uncertainty" is a well-defined numerical measure that is reported along with test results. It's simply the "plus or minus" value that accompanies many different types of measures, representing the outer limits of the likely true value of the measurement. Exhibit B, excerpted from a set of Hakes leachate results in which Lead-214 and Bismuth-214 are high (6/6/2017 Cell 8B), provides some examples. As seen in Exhibit B, results for Bismuth-214 and Lead-214 are both in the neighborhood of 6000 pCi/L, which is well above the Minimum Detectable Concentration (the MDC is in the neighborhood of 70 or 84). The uncertainty is high (plus or minus about 660 pCi/L), indicating that it's highly likely that the real result for either Bismuth-214 and Lead-214 is about 660 pCi/L higher than 6000 pCi/L, or about 660 pCi/L lower than 6000 pCi/L, or anywhere in between.[3] There would be no rational basis for rejecting these reported values (consisting of the combination of measured activity, uncertainty, and MDC) as "uncertain."

Similarly, the 11/18/2016 Hakes leachate results shown in Exhibit B for dissolved Bismuth-214 and dissolved Lead-214 are both in the neighborhood of 3900 pCi/L, which is well above the Minimum Detectable Concentration (the MDC is in the neighborhood of 49 or 59). The uncertainty is high (plus or minus about 420 pCi/L), so it's highly likely that the real result for either radionuclide is about 420 pCi/L higher than 3900 pCi/L, or about 420 pCi/L lower than 3900 pCi/L, or anywhere in between.[4] Here again, unless there is some unreported complication, these reported values (consisting of the combination of measured activity, uncertainty, and MDC) must be regarded as valid.

The other Method 901.1 test results shown in Exhibit B have measured activities that are variously reported as being above, about equal to, or below the MDC. Where the uncertainty is greater than the measured activity, the lower limit for the likely real activity will be a negative number – which isn't physically possible but reflects the difficulty (impossibility) of getting a realistic test result when the activity is below the MDC. As can be seen in Exhibit B, Method 903.1 provides somewhat better (i.e., more valid or trustworthy) results for the relatively low levels of radium found in the leachate samples. This is true simply because its MDC tends to be lower than the MDC for Method 901.1, making Method 903.1 a more suitable radium test at these low radium levels. However, if a substantially higher level of radium were present in one of these leachate samples, it would exceed the MDC and should show up "loud and clear" in the Method 901.1 test result. In this sense, all of the current Method 901.1 test results for radium in Hakes leachate provide a redundant safeguard (redundant with Method 903.1) that confirms the relatively low radium levels.

Returning to the DEC/CoPhysics allegations about uncertainty associated with Method 901.1, and likewise to the cloudy logic about Method 901.1 in DEC's recent revision of Parts 360-363 (see Exhibit A), the entire concern seems to revolve around test protocols for samples in which *radium* levels are below the Method 901.1 MDC. Granted, radium levels have tended to be

[3] These values are expressed approximately for the sake of discussion. See Exhibit B and its source for the actual numbers under discussion here.
[4] See footnote 3.

below the Method 901.1 MDC, but this fact provides no sound basis for thinking that the test is dispensable because levels of radium – and other radionuclides – would always remain below the MDC. The excerpted test results in Exhibit B show why this is so. In a competent regulatory regime it's important to know when radionuclide levels in a sample are low, and also when they're high.

As noted above, there's always a remote possibility of an unreported complication that could render reported test results unreliable – but in a competent regulatory regime there's no reasonable basis for suspecting unreported complications. Laboratory certification programs such as the Environmental Laboratory Approval Program (ELAP) take proactive steps to avoid such complications. ELAP is New York's own codification of laboratory standards based on the National Environmental Laboratory Accreditation Conference (NELAC) standard.[5] It specifies that laboratory test results shall be reported accurately, clearly, unambiguously and objectively; that uncertainties shall be identified and reported; that periodic audits must evaluate whether there are any findings that cast doubt on the effectiveness of the operations or on the correctness or validity of the laboratory's environmental test results; and that a laboratory shall take timely corrective action and shall notify clients if investigations show that the laboratory results may have been affected. Relevant portions of the ELAP standards are quoted below:

> 3.10.1 General
>
> The results of each test, or series of environmental tests carried out by the laboratory shall be reported accurately, clearly, unambiguously and objectively, and in accordance with any specific instructions in the environmental test....

ELAP Certification Manual (https://www.wadsworth.org/sites/default/files/WebDoc/1076921392/210.pdf), 5/6/08, page 40 of 69.

> 3.4.6 Estimation of Uncertainty of Measurement
>
> 3.4.6.1 Environmental testing laboratories shall have and shall apply procedures for estimating uncertainty of measurement. In certain cases the nature of the test method may preclude rigorous, metrologically and statistically valid, calculation of uncertainty of measurement. In these cases the laboratory shall at least attempt to identify all the components of uncertainty and make a reasonable estimation, and shall ensure that the form of reporting of the result does not give a wrong impression of the uncertainty.

[5] See the Environmental Laboratory Approval Program (ELAP) Certification Manual, online at https://www.wadsworth.org/sites/default/files/WebDoc/1076921392/210.pdf, which states that "The New York State Department of Health, Wadsworth Center, Environmental Laboratory Approval Program (ELAP) has adopted as its Quality System Standard the current version of the National Environmental Laboratory Accreditation Conference (NELAC) standard. This is Chapter 5 of the 2003 NELAC standards, and it is reproduced herein in an edited form." ELAP Certification Manual, 5/6/08, page 1 of 69.

Reasonable estimation shall be based on knowledge of the performance of the method and on the measurement scope and shall make use of, for example, previous experience and validation data.

In those cases where a well-recognized test method specifies limits to the values of the major sources of uncertainty of measurement and specifies the form of presentation of calculated results, the laboratory is considered to have satisfied this clause by following the test method and reporting instructions (see 3.10).

3.4.6.2 When estimating the uncertainty of measurement, all uncertainty components which are of importance in the given situation shall be taken into account using appropriate methods of analysis.

Id., page 26 of 69.

2.13 Internal Audits

2.13.1 The laboratory shall periodically, in accordance with a predetermined schedule and procedure, and at least annually, conduct internal audits of its activities to verify that its operations continue to comply with the requirements of the quality system and this Standard. The internal audit program shall address all elements of the quality system, including the environmental testing activities. It is the responsibility of the quality manager to plan and organize audits as required by the schedule and requested by management. Such audits shall be carried out by trained and qualified personnel who are, wherever resources permit, independent of the activity to be audited. Personnel shall not audit their own activities, except when it can be demonstrated that an effective audit will be carried out.

2.13.2 When audit findings cast doubt on the effectiveness of the operations or on the correctness or validity of the laboratory's environmental test results, the laboratory shall take timely corrective action and shall notify clients, in writing, if the investigations show that the laboratory results may have been affected.

The laboratory shall notify clients promptly, in writing, of any event such as the identification of defective measuring or test equipment that casts doubt on the validity of results given in any test report or test certificate or amendment to a report or certificate.

Id., page 17 of 69.

Under this protocol, test results and associated uncertainties must be clearly identified and accurately reported. If there is doubt about the validity of results, test labs are required to investigate, take corrective action, and provide notification of any laboratory results that may have been affected. The applicability of this protocol to landfills in New York is expressed in 6 NYCRR 363-4.6(g)(4)(i), which requires that "Laboratory analyses must be performed by a laboratory currently certified under the appropriate approval categories by the New York State Department of Health's Environmental Laboratory Approval Program (ELAP)." There is no

place within such a protocol for vague, undocumented assertions about "uncertainty" of laboratory test results.

Another misstatement by CoPhysics is that "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." (CoPhysics Report at 30.) This is an incorrect statement. EPA Method 901.1 is clearly an analysis method for water. See pp. 21-25 of the EPA report entitled *Prescribed Procedures for Measurement of Radioactivity in Drinking Water*, EPA-600/4-80-032, August 1980.[6] This report is cited as an authoritative source in current NYS landfill regulations (6 NYCRR 360.3(b)(5) and footnote 14 of 6 NYCRR 363-4.6); hence DEC should be well aware of the report and the fact that Method 901.1 is described therein as an analysis method for water.

C. A valid method of back-calculation (decay-correction) has been used by Sierra Club's expert(s) to determine that the radon level in leachate has been intermittently as high as approx. 270,000 or 275,000 pCi/L radon

The method of calculating that radon in Hakes leachate has intermittently been as high as 270,000 or 275,000 pCi/L is valid and correct,[7] and the uncertainty associated with the method is very low and well-bounded. CoPhysics acknowledges that:

> 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 #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....

CoPhysics Report at 29.

CoPhysics proceeds to make various explanations that are incorrect, misleading, and/or irrelevant.

First, CoPhysics claims that "Past leachate sampling and analysis methods were never designed to be used for radon assessment." (Id.) This claim about the purpose of past samples ("never designed to be used for radon assessment") is not supported by the Project Narrative from one of the past tests. The Project Narrative uses the word "ingrowth," referring to creation of Lead-214 and Bismuth-214 from radon decay within the sample.[8] In any case, it does not matter whether

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[6] The report is posted on the EPA website and may be accessed at https://tinyurl.com/ydg2rtqg or https://nepis.epa.gov/Exe/ZyPDF.cgi/30000QHM.PDF?Dockey=30000QHM.PDF.

[7] My January 18, 2018 affidavit used 270,000 pCi/L as an approximation. CoPhysics uses 275,000 pCi/L as an approximation. Either value serves the purpose of discussion.

[8] The word "ingrowth," referring to creation of Lead-214 and Bismuth-214 from radon decay, was applied to at least one set of past leachate samples submitted for analysis. The Pace Analytical "Project Narrative" sheet dated Nov. 25, 2014 for Method 901.1 analysis of the Hakes leachate samples collected

past samples were collected and analyzed for the specific purpose of assessing radon; they are well-suited for this purpose. Prior to 2018, the Hakes leachate sampling and analysis methods did not test for either radon or Lead-210. Despite the absence of radon data*, it is possible and scientifically valid* (see further discussion below) *to back-calculate or decay-correct from the Lead-214 and Bismuth-214 data to determine the Radon-222 concentration in leachate at the time of sample collection*. The absence of Lead-210 data is unfortunate because such data would have been very useful for double-checking the back-calculated (decay-corrected) radon concentrations such as 270,000 or 275,000 pCi/L – but the back-calculation/decay-correction method is entirely correct regardless of whether it can be double-checked by Lead-210 data. At best, the claim that the leachate test results were "never designed" for radon assessment by back-calculation/decay-correction is irrelevant and misleading.

Next, CoPhysics claims (id.) to "have discussed these unusual results [back-calculation/decay-correction of past leachate sampling and analysis methods for the purpose of radon assessment] 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."

The claims that "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" and that "the 275,000 pCi/L calculation cannot be relied upon as an accurate estimation of radon and progeny in the original on-site samples" are both incorrect, as explained below.

Here is why these claims are incorrect. As a preliminary matter, it is reasonable to make three assumptions. These assumptions, apparently undisputed, are a necessary part of the foundation for back-calculation (decay-correction) of radon activity within the sealed sample container:

- First, the test results reported semiannually through 2017 for the Hakes leachate samples, including the radium test results[9] and the ~6000 pCi/L results for Bismuth-214 and Lead-214 in two samples (Hakes Cell #5 on 11/11/14 and Hakes Cell #8 on 6/6/17), are *reliable measures within the uncertainty values reported by the lab*. One indication of

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Nov. 11, 2014, refers to the samples as "901.1 Gamma Spec INGROWTH." This terminology implies that the purpose was to understand radionuclide ingrowth during the sample holding period. Such a purpose is inseparable from radon assessment during the sample holding period, including the endpoints of that period (the sample collection date and testing date).

[9] My January 18, 2018 affidavit at ¶¶ 36-41 expresses the possibility that the radium measurements in leachate samples may be in error. While that possibility needs to be recognized as part of the logic presented there, the possibility appears remote in view of the consistently low radium measurements by both Method 901.1 and 903.1. Thus, the most likely possibility is that the reported results are accurate within the reported uncertainties; that the radium in leachate is low, as reported; that the Lead-214 and Bismuth-214 in leachate are intermittently high, as reported; and that radium elsewhere in the landfill (not in the leachate) remains unmeasured and unknown. This last conclusion ("unmeasured and unknown") is discussed and supported in this memo, in my January 2018 affidavit, etc.

the reliability of these high Lead-214 and Bismuth-214 results is the absence of any cautionary "flag" attached to these values in the analytical lab's report. Another is the mutual corroboration of the independent measurements of Lead-214 and Bismuth-214 in a given sample. When one of these radionuclides is high, the other is also high, as would be expected due to secular equilibrium in samples that had been sealed for 21 days.

- Second, in accordance with secular equilibrium, the activities of Radon-222, Lead-214, and Bismuth-214 are all approximately the same after 21 days in a sealed container. Consequently, the reported activities and associated uncertainties for Lead-214 and/or Bismuth-214 in a given sample can be used as reasonable approximations of the activity and associated uncertainty of Radon-222 in the same sample.

- Third, the activity and associated uncertainty for a given radionuclide can be converted with negligible error from pCi to other units such as mass or moles or number of atoms (nuclei) of that radionuclide, or can be converted back to pCi, in accordance with the radionuclide's specific activity and Avogadro's number. See especially the USGS report attached as Exhibit C, at 1.

In summary, the Lead-214 and Bismuth-214 lab results (~6000 pCi/L) and associated uncertainty values can be considered accurate, within the accepted meaning of "accurate," at the time of sample analysis.[10] In turn, these results and associated uncertainty values provide a very good approximation of the activity (alternatively expressed as mass, moles, or number of atoms) and the associated uncertainty of Radon-222, per unit volume of sample, *at the time of sample analysis*.

The next step (looking backward 21 days) is to determine the activity and associated uncertainty of Radon-222, per unit volume of sample, *at the time of sample collection*. In this process of back-calculating (decay-correcting) Radon-222 in a sealed container, there are no uncertainties due to sample counting and other measurement procedures. Such measurement-based uncertainties *have already been accounted for* in the uncertainty values that the lab reported along with the ~6000 pCi/L test results. Hence, for a sample held in a sealed container for 21 days, the only uncertainties in back-calculating/decay-correcting are 1) the purely statistical uncertainty of radioactive decay, based entirely on well-established equations, and 2) the uncertainty in the half-life of Radon-222 based on historic (not current test-specific) measurements. As explained below, both of these uncertainties are extremely small, well understood, and well-bounded. Thus, in the context of the Hakes samples, it is incorrect to say that "decay correction of several orders of magnitude would result in a multiplication of the uncertainties to unreliable levels" and that the resulting calculation "cannot be relied upon as an accurate estimation of radon and progeny..."

[10] For an overview of what's meant by "accurate within" the reported uncertainty, see USGS report, attached as Exhibit C, at 3-4.

The well-known statistical uncertainty of radioactive decay in a sealed container can be understood from the radioactive decay law:

$$N = N_0 \exp\left(\frac{-\ln(2)\,\Delta t}{T_{½}}\right) \quad (1)$$

$$S.D. = \sqrt{N} \quad (2)$$

where N_0 is the number of atoms (nuclei) of Radon-222 initially present at $t = 0$; N is the mean number of atoms (nuclei) of Radon-222 present after an interval Δt; and $T_{½}$ is the half-life of Radon-222. The standard deviation of N, designated *S.D.* in Equation (2), is the square root of N in accordance with the well-known relationship (variance = mean) in a Poisson process such as radioactive decay. The statistical uncertainty of radioactive decay of Radon-222 in a Hakes leachate sample that remains sealed for $\Delta t = 21$ days is thus expressed by *S.D.* in Equation (2), and this uncertainty, which incorporates the very small uncertainty in the half-life of Radon-222 ($T_{½} = 3.8232 \pm 0.0008$ days[11]), constitutes the only substantial uncertainty in back-calculating (decay-correcting) for $\Delta t = 21$ days. Ingrowth of radon from radium in the sample might also be accounted for – but, while this could readily be included in the present calculations, it is omitted here as a reasonable simplification because the test results consistently show a relatively small quantity of radium in the leachate samples, including those collected from Hakes Cell #5 on 11/11/14 and Hakes Cell #8 on 6/6/17.

The only remaining question in this uncertainty analysis is the number of Radon-222 atoms (nuclei) that were present in the Hakes leachate sample container, either at $t = 0$ or $t = 21$ days. Knowing either the value of N_0 or the value of N will serve essentially the same purpose since the two values are interrelated by Equation (1). The size of the sample container is not clearly specified in the Hakes leachate analytical reports but is apparently in the range of 250 mL (one-quarter liter) to one liter.[12] The sample container size is a variable that needs to be quantified (the values of N and N_0 depend on it), but, as will be shown below in Tables 2-3, the uncertainty in the back-calculation/decay-correction process is very low regardless of whether the sample container size is a fraction of a liter or a full liter.

Table 1 provides a simplified illustration of these relationships, using the approximate values from my January 18, 2018 affidavit (~270,000 pCi/L Radon-222 at time of sample collection in samples that contained ~6000 pCi/L Lead-214 and Bismuth-214 at time of sample testing), but note that Table 1 does not yet show any of the uncertainties. (Table 2 will address the uncertainties in detail.) Table 1 shows N and N_0 values (based on 6000 pCi/L and Equation (1)) for either 250-mL or 1-L sample containers. Tables 2-3 will provide numerical details for $\sqrt{N}$,

[11] Source: http://www.nucleide.org/DDEP_WG/Nuclides/Rn-222.lara.txt.

[12] In the analytical results reported for 4Q 2014 Hakes leachate, page 2 of the Pace Analytical "Sample Condition Upon Receipt" form indicates "Glass Jar," with 120 [mL] and 250 [mL] circled. The analytical results reported for 2Q 2017 Hakes leachate do not appear to identify sample volume but say that "12 mls of nitric acid were added to the sample to meet the sample preservation requirement of pH <2 for radiochemistry analysis" for the Cell 8B samples tested by Method 901.1 (and similarly for other 2Q 2017 samples), implying a sample volume that is a substantial fraction of a liter, based on an accepted practice of adding 15 mL of nitric acid per liter of sample.

the standard deviation of a radioactive decay process as defined in Equation (2), where $\sqrt{N}$ expresses the only substantial uncertainty in back-calculating/decay-correcting the activity of Radon-222 in a sealed sample container for $\Delta t = 21$ days.

Table 1: Approximate numerical relationships in samples with high Pb-214 and Bi-214

		^	~6000	pCi/L	Bi-214 at time of sample testing (t = 21 days)
		DECAY			
		DIRECTION	~6000	pCi/L	Pb-214 at time of sample testing (t = 21 days)
		^			
			~6000	pCi/L	Rn-222 at time of sample testing (t = 21 days)
Avogadro's Number =	6.02E+23	nuclei/mol	3.90E-14	g/L	
	2.71E+21	nuclei/g of Rn-222	1.06E+08	nuclei/L	N per liter at time of sample testing (t = 21 days)
			2.64E+07	nuclei/quarter liter	N per quarter liter at time of sample testing (t = 21 days)
Rn-222 specific activity =	5.69E+15	Bq/g			
	1.54E+17	pCi/g			
			~270,000	pCi/L	Rn-222 at time of sample collection (t = 0)
Rn-222 half-life =	3.8232	days	1.76E-12	g/L	
N/N0 =	~0.022222		4.76E+09	nuclei/L	N0 per liter at time of sample collection (t = 0)
			1.19E+09	nuclei/quarter liter	N0 per quarter liter at time of sample collection (t = 0)

Table 2 shows Pb-214 and Bi-214 results and associated uncertainties reported for Hakes Cell #5 leachate on 11/11/14 and Hakes Cell #8 leachate on 6/6/17. The Bi-214 values are shown only for comparison, while the Pb-214 values are used as the basis for the Radon-222 values.

In Table 2, the last four blocks of values show the decay relationships for various initial Radon-222 activities ranging from 248,183 to 340,665 pCi/L. These various initial values, representing Radon-222 activity in leachate at the time of sample collection ($t = 0$), are chosen such that their 21-day decay-corrected values (in bold) match the values (also in bold) that are known from the Lead-214 data. The decays calculated for the various initial values in Table 2 incorporate the quantified uncertainties in half-life and container size, so that these uncertainties are accounted in combination with the statistical decay-process uncertainty and with the analytical-test uncertainties shown at the top of the table. Table 2 thus shows the upper and lower bounds for Radon-222 activity in leachate at the time of sample collection (248,183 to 340,665 pCi/L overall, encompassing both test dates), based on the reported data and the four types of uncertainties that are accounted for in the table.

Table 2 is detailed and is the source of the values presented in Table 3.

Table 2: Numerical relationships based on reported Pb-214 data

11/11/2014			6/6/2017				
6221.7	±	670.09	6067.2	±	653.72	pCi/L	Bi-214 at time of sample testing (t = 21 days), as reported
6819.9	±	738.23	6183.9	±	666.77	pCi/L	Pb-214 at time of sample testing (t = 21 days), as reported
6081.67	to	7558.13	5517.13	to	6850.67	pCi/L	Pb-214 at time of sample testing (t = 21 days), range
6081.67	to	**7558.13**	**5517.13**	to	**6850.67**	pCi/L	Rn-222 at time of sample testing (t = 21 days), range based on Pb-214
3.95E-14	to	4.91E-14	3.59E-14	to	4.45E-14	g/L	
1.07E+08	to	1.33E+08	9.73E+07	to	1.21E+08	nuclei/L	N per liter at time of sample testing (t = 21 days)
2.68E+07	to	3.33E+07	2.43E+07	to	3.02E+07	nuclei/quarter liter	N per quarter liter at time of sample testing (t = 21 days)
							Rn-222 half-life = 3.8232 ± 0.0008 days
							USING 3.8240-day Rn-222 HALF-LIFE, HENCE N/N0 = 0.022226:
273,607	to	340,093	248,208	to	308,261	pCi/L	Rn-222 at time of sample collection (t = 0)
1.78E-12	to	2.21E-12	1.61E-12	to	2.00E-12	g/L	
4.82E+09	to	6.00E+09	4.38E+09	to	5.44E+09	nuclei/L	N0 per liter at time of sample collection (t = 0)
1.07E+08	to	1.33E+08	9.73E+07	to	1.21E+08	nuclei/L	Calculated N per liter at time of sample testing (t = 21 days)
1.04E+04	to	1.15E+04	9.86E+03	to	1.10E+04	nuclei/L	S.D. of N per liter at time of sample testing (t = 21 days)*
1.07E+08		1.33E+08	9.73E+07		1.21E+08	nuclei/L	N ± S.D. per liter at time of sample testing (t = 21 days)**
3.95E-14		4.91E-14	3.59E-14		4.45E-14	g/L	Ditto expressed as g/L
6081.67		**7558.13**	**5517.13**		**6850.67**	pCi/L	Ditto expressed as pCi/L
273,581	to	340,123	248,183	to	308,289	pCi/L	Rn-222 at time of sample collection (t = 0)
1.78E-12	to	2.21E-12	1.61E-12	to	2.00E-12	g/L	
4.82E+09	to	6.00E+09	4.38E+09	to	5.44E+09	nuclei/L	N0 per liter at time of sample collection (t = 0)
1.21E+09	to	1.50E+09	1.09E+09	to	1.36E+09	nuclei/quarter liter	N0 per quarter liter at time of sample collection (t = 0)
2.68E+07	to	3.33E+07	2.43E+07	to	3.02E+07	nuclei/quarter liter	Calculated N per quarter liter at time of sample testing (t = 21 days)
5.18E+03	to	5.77E+03	4.93E+03	to	5.50E+03	nuclei/quarter liter	S.D. of N per quarter liter at time of sample testing (t = 21 days)*
2.68E+07		3.33E+07	2.43E+07		3.02E+07	nuclei/quarter liter	N ± S.D. per quarter liter at time of sample testing (t = 21 days)**
9.88E-15		1.23E-14	8.97E-15		1.11E-14	g/quarter liter	Ditto expressed as g per quarter liter
3.95E-14		4.91E-14	3.59E-14		4.45E-14	g/L	Ditto expressed as g/L
6081.67		**7558.13**	**5517.13**		**6850.67**	pCi/L	Ditto expressed as pCi/L
							USING 3.8224-day Rn-222 HALF-LIFE, HENCE N/N0 = 0.022190:
274,043	to	340,636	248,604	to	308,753	pCi/L	Rn-222 at time of sample collection (t = 0)
1.78E-12	to	2.21E-12	1.62E-12	to	2.01E-12	g/L	
4.83E+09	to	6.01E+09	4.38E+09	to	5.44E+09	nuclei/L	N0 per liter at time of sample collection (t = 0)
1.07E+08	to	1.33E+08	9.73E+07	to	1.21E+08	nuclei/L	Calculated N per liter at time of sample testing (t = 21 days)
1.04E+04	to	1.15E+04	9.86E+03	to	1.10E+04	nuclei/L	S.D. of N per liter at time of sample testing (t = 21 days)*
1.07E+08		1.33E+08	9.73E+07		1.21E+08	nuclei/L	N ± S.D. per liter at time of sample testing (t = 21 days)**
3.95E-14		4.91E-14	3.59E-14		4.45E-14	g/L	Ditto expressed as g/L
6081.67		**7558.13**	**5517.13**		**6850.67**	pCi/L	Ditto expressed as pCi/L
274,017	to	340,665	248,578	to	308,781	pCi/L	Rn-222 at time of sample collection (t = 0)
1.78E-12	to	2.21E-12	1.62E-12	to	2.01E-12	g/L	
4.83E+09	to	6.01E+09	4.38E+09	to	5.44E+09	nuclei/L	N0 per liter at time of sample collection (t = 0)
1.21E+09	to	1.50E+09	1.10E+09	to	1.36E+09	nuclei/quarter liter	N0 per quarter liter at time of sample collection (t = 0)
2.68E+07	to	3.33E+07	2.43E+07	to	3.02E+07	nuclei/quarter liter	Calculated N per quarter liter at time of sample testing (t = 21 days)
5.18E+03	to	5.77E+03	4.93E+03	to	5.50E+03	nuclei/quarter liter	S.D. of N per quarter liter at time of sample testing (t = 21 days)*
2.68E+07		3.33E+07	2.43E+07		3.02E+07	nuclei/quarter liter	N ± S.D. per quarter liter at time of sample testing (t = 21 days)**
9.88E-15		1.23E-14	8.97E-15		1.11E-14	g/quarter liter	Ditto expressed as g per quarter liter
3.95E-14		4.91E-14	3.59E-14		4.45E-14	g/L	Ditto expressed as g/L
6081.67		**7558.13**	**5517.13**		**6850.67**	pCi/L	Ditto expressed as pCi/L

* Standard deviation (S.D.) of N is square root of N, in accordance with Equation (2)

** Values of N plus or minus S.D. are calculated as either plus or minus, whichever maximizes the range or spread of Rn-222 at time of sample collection

Table 3: Summary of 21-day decay statistics for Radon-222

11/11/2014			6/6/2017				
6221.7	±	670.09	6067.2	±	653.72	pCi/L	Bi-214 at time of sample testing (t = 21 days), as reported
6819.9	±	738.23	6183.9	±	666.77	pCi/L	Pb-214 at time of sample testing (t = 21 days), as reported
STANDARD DEVIATION OF N FOR Rn-222 IN 1-liter SAMPLE SEALED FOR 21 days, AS DERIVED IN TABLE 2:							
1.04E+04		1.15E+04	9.86E+03		1.10E+04	nuclei/L	S.D. of N per liter at time of sample testing (t = 21 days)
3.82E-18		4.26E-18	3.64E-18		4.05E-18	g/L	Ditto expressed as g/L
0.59		**0.65**	**0.56**		**0.62**	pCi/L	Ditto expressed as pCi/L
STANDARD DEVIATION OF N FOR Rn-222 IN 250-mL SAMPLE SEALED FOR 21 days, AS DERIVED IN TABLE 2:							
5.18E+03		5.77E+03	4.93E+03		5.50E+03	nuclei/quarter liter	S.D. of N per quarter liter at time of sample testing (t = 21 days)
1.91E-18		2.13E-18	1.82E-18		2.03E-18	g/quarter liter	Ditto expressed as g per quarter liter
7.63E-18		8.51E-18	7.27E-18		8.10E-18	g/L	Ditto expressed as g/L
1.17		**1.31**	**1.12**		**1.25**	pCi/L	Ditto expressed as pCi/L
SUMMARY OF DECAY STATISTICS, EXPRESSED IN pCi/L, FROM LOWER FOUR BLOCKS OF VALUES IN TABLE 2:							
273,607	to	340,093	248,208	to	308,261	pCi/L	Rn-222 at time of sample collection (t = 0)
6081.08 ± 0.59		7558.78 ± 0.65	5516.57 ± 0.56		6851.30 ± 0.62	pCi/L	Rn-222 at time of sample testing (t = 21 days)
273,581	to	340,123	248,183	to	308,289	pCi/L	Rn-222 at time of sample collection (t = 0)
6080.50 ± 1.17		7559.44 ± 1.31	5516.01 ± 1.12		6851.92 ± 1.25	pCi/L	Rn-222 at time of sample testing (t = 21 days)
274,043	to	340,636	248,604	to	308,753	pCi/L	Rn-222 at time of sample collection (t = 0)
6081.08 ± 0.59		7558.79 ± 0.65	5516.57 ± 0.56		6851.29 ± 0.62	pCi/L	Rn-222 at time of sample testing (t = 21 days)
274,017	to	340,665	248,578	to	308,781	pCi/L	Rn-222 at time of sample collection (t = 0)
6080.49 ± 1.17		7559.44 ± 1.31	5516.01 ± 1.12		6851.92 ± 1.25	pCi/L	Rn-222 at time of sample testing (t = 21 days)

Table 3 shows that the uncertainty (standard deviation) for the decay of Radon-222 in a sealed sample container for 21 days is on the order of 1 pCi/L – which is essentially negligible in this context. This statistical uncertainty is a consequence of the decay relationships expressed in Equations (1) and (2) which are well-established – beyond any reasonable doubt – for any such Poisson process that exhibits exponential decay. Thus, any claim that "decay correction of several orders of magnitude would result in a multiplication of the uncertainties to unreliable levels" or that the resulting calculation "cannot be relied upon as an accurate estimation of radon and progeny..." is entirely incorrect.

As can be seen from Tables 2 and 3, the simplified version of decay correction presented in my January 18, 2018 affidavit (see Table 1 above) is an *understatement* of the Radon-222 activity in the 11/11/14 Cell #5 and 6/6/17 Cell #8 leachate samples at the time of sample collection. As shown in Table 2, *the Radon-222 activity in these leachate samples may have been as high as 340,665 pCi/L or as low as 248,183 pCi/L*, depending on the uncertainties that are taken into

account. There is no other credible interpretation of the reported Pb-214 and Bi-214 data for 11/11/14 Cell #5 and 6/6/17 Cell #8 leachate.

Tables 2 and 3 could be recalculated, as needed, with uncertainties representing greater than 1 sigma (e.g., 1.96 sigma). If this were done, it would expand the bounds for Radon-222 activity in leachate at the time of sample collection (currently 248,183 to 340,665 pCi/L overall, encompassing both test dates), thereby lowering the lower bound and raising the upper bound, while leaving the mean or central value essentially unchanged.

Uncertainties in the 21-day back-calculation/decay-correction process have been worked out numerically in the above paragraphs and Tables 2-3. The same result could be obtained from the principles of error propagation by applying the standard equation for a function R of variables X, Y, etc., where the uncertainty δR in R can be calculated from the uncertainties δX, δY,… in X, Y,…, respectively:

$$R = R(X, Y, \dots) \tag{3}$$

$$\delta R = \sqrt{\left(\frac{\partial R}{\partial X}\delta X\right)^2 + \left(\frac{\partial R}{\partial Y}\delta Y\right)^2 + \cdots} \tag{4}$$

The results of such error-propagation calculation would be the same as the numerically-derived results presented above.

In summary, ~270,000 pCi/L Radon-222 remains a very good and entirely supported approximation for Hakes Cell #5 leachate on 11/11/14 and Cell #8 leachate on 6/6/17. There are at least two reasons why such high radon activity in leachate can't be dismissed as a fluke or artifact. One is simply the mutual corroboration of Lead-214 and Bismuth-214 results: when one is high, the other is also high. The other reason is the relatively frequent occurrence of these sporadic "highs." The highest examples are of course from Cell #5 leachate on 11/11/14 and Cell #8 leachate on 6/6/17, but other mysteriously high test results for Lead-214 and Bismuth-214 include:

- ~3900 pCi/L from Cell #8B on 11/18/16 (implying ~175,000 pCi/L radon in leachate),
- ~2500 pCi/L from Cell #4 on 6/6/17 (implying ~112,000 pCi/L radon in leachate),
- ~1800 pCi/L from Cell #3 on 6/6/17 (implying ~81,000 pCi/L radon in leachate),
- and two examples of ~1000 pCi/L from *Chemung* landfill, as seen above on page 6.

All of these are far above the results normally reported for Lead-214 and Bismuth-214 in Hakes leachate samples. There is, however, a reasonable question of whether the normally low results for Lead-214 and Bismuth-214 are valid. The normally low results may not be valid (i.e., may not be representative of the sampled leachate and its 21-day ingrowth and decay) if the sample containers are not well sealed, allowing radon to leak out of some of the sample jars.

D. A valid method of calculation has been used by Sierra Club's expert(s) to determine that the radon level in landfill gas has likely been as high as approx. 1.05 million pCi/L radon

Here again, *the method is valid*. Specifically, the calculation that radon in landfill gas has likely been as high as ~1.05 million pCi/L is valid and correct.

As outlined in my January 18, 2018 affidavit, water that contains ~270,000 pCi/L dissolved radon is at equilibrium with an overlying air-radon mixture that contains ~1.05 million pCi/L radon. If leachate and landfill gas are reasonable analogs of water and air, then leachate that contains ~270,000 pCi/L dissolved radon is approximately at equilibrium with an overlying landfill gas mixture that contains ~1.05 million pCi/L radon.

If the radon in leachate is only intermittently high, then an equilibrium relationship cannot provide a simple answer about radon activity in overlying landfill gas and how it may vary over time – yet the equilibrium relationship does contribute to an important general truth about the concentration gradient needed to transfer radon across an interface between landfill gas and leachate.

The question is how a sufficient quantity of radon was able to dissolve in leachate to produce a concentration of ~270,000 pCi/L radon in the leachate.[13] This is a crucial question regardless of whether the level of dissolved radon remains continually high or is only intermittently at a level of ~270,000 pCi/L. There are apparently only two possible answers.

The most likely explanation is that the parent radium remains relatively "high and dry," immersed primarily in landfill gas rather than any hydrologically connected pool or stream of leachate, such that the ingrowth of radon occurs mainly within the landfill gas. In this case, radon must migrate across the landfill gas/leachate interface in order to dissolve into the leachate and reach a concentration of ~270,000 pCi/L. Such migration will occur only if there's a sufficient concentration gradient across the interface to make it happen, which means that the landfill gas at the interface must at least briefly contain more than about 1.05 million pCi/L radon in order to carry enough radon into the leachate to reach ~270,000 pCi/L dissolved radon. This must be the case, given the contradictions to the other answer. If so, there is a need for additional testing to characterize the source and migration of the radon, including tests to identify *how much radium is in the landfill* and *what the radon flow pathways are*.

The less likely explanation is that the parent radium is immersed in the leachate, such that the ingrowth of radon occurs within the leachate. This would not require any radon to migrate across an interface from landfill gas to leachate. Some radon would presumably migrate in the

[13] As noted above, the activity of a given radionuclide can be converted from pCi to other units such as mass or moles or number of atoms (nuclei) of that radionuclide, or can be converted back to pCi, in accordance with the radionuclide's specific activity and Avogadro's number. In this manner, activity per unit volume can be readily converted to concentration and vice versa.

opposite direction by offgassing from the leachate into the landfill gas – at least intermittently when the leachate ranged up to ~270,000 pCi/L dissolved radon – resulting in some concentration of radon in the landfill gas, probably much less than ~1.05 million pCi/L. However, there are two factors that disfavor or contradict this possibility. One is that immersion of radium-bearing waste in leachate is contrary to good landfill practice; any radium should be relatively "high and dry" in the landfill.[14] The other contradiction is that leachate test results consistently show low levels of radium, strongly implying that the contact between leachate and radium (and/or its soluble compounds) is minimal, i.e., too low to account for radon levels ranging up to ~270,000 pCi/L in leachate. Arguments could conceivably be made that radon generated from small quantities of radium is somehow concentrating itself at certain points in space and time, but such arguments are usually not thermodynamically plausible.

E. The significance or physical interpretation of the fact that leachate test results are only intermittently high

There are three possible explanations for why the high levels of Lead-214, Bismuth-214, and radon are only intermittently high:

- Radon is continually high in Hakes leachate but is lost from poorly sealed sample jars,
- Radon in leachate is intermittently high due to *fluctuations in the radon flow path from radium to leachate* within the landfill, or
- Radon in leachate is intermittently high due to *variations in the tightness of the landfill cap*, allowing radon to escape most of the time but causing radon to accumulate when the cap is tight.

The first of these possible explanations (radon in leachate is continually high but lost from poorly sealed sample jars) is unlikely, based partly on the reasonable presumption that sample collection has been done professionally and partly on the recent Lead-210 results reported by CoPhysics. The recent Lead-210 results, while uninformative about prior leachate samples showing intermittently high Lead-214 and Bismuth-214, do show that radon cannot have been continually high in the leachate (because otherwise Lead-210 would be detected at a higher level than in the recent Lead-210 results reported by CoPhysics).

In the second of these possible explanations, there is continual radon ingrowth from radium within the landfill, resulting in localized mixing of radon with landfill gas, but there is no continuously open circulation within the landfill that would allow such localized pockets of radon-landfill gas to come into contact with the leachate. Most of the time, flow paths within the landfill would be sufficiently constricted that most of the radon ingrowth would decay to its solid (less mobile) progeny before reaching the leachate – but at other times, as shown by the

[14] See also 6 NYCRR 363-7.1(a)(3), which requires that "Drilling and production waste may not be placed within 6 feet of the leachate collection and removal system or within 10 feet of any final cover."

intermittently high readings in the test data, flow paths within the landfill are able to convey relatively large quantities of the radon toward and into the leachate. Given the magnitude of the intermittently high readings and the currently uncharacterized impacts, there is a need for additional testing to characterize the source and migration of the radon, including tests to identify how much radium is in the landfill and what the radon flow pathways are.

In the third of these possible explanations, there is continual radon ingrowth from radium within the landfill, resulting in a mixture of radon with landfill gas that periodically comes into contact with the leachate – but the radon pathway leading outward from the parent radium is highly variable. Most of the time, a radon-landfill gas mixture is *escaping freely into the atmosphere and effectively bypassing the leachate* in this scenario – but at other times, as shown by the intermittently high readings in the test data, the landfill cap or other barrier is confining the radon-landfill gas mixture in proximity to the leachate, allowing and causing substantial quantities of radon to dissolve into the leachate. Given the high activity (~1 million pCi/L) of the plume of radon-landfill gas leaking from the landfill most of the time under this scenario, there is a need for additional testing to characterize the source, migration, and impacts of the radon, including tests to identify how much radium is in the landfill and what the radon flow pathways are.

For any of these possible interpretations of the intermittently high results, it may be useful to determine whether the parent radium is mostly naturally occurring or mostly from radium-bearing waste disposal. However, neither outcome can ignore the question of health effects, nor can either outcome allow the intermittently high radionuclide levels to be dismissed as inconsequential. If naturally occurring, the intermittently high results raise a fundamental question about whether the landfill can be reasonably characterized, modeled, analyzed, and monitored. If mostly from radium-bearing waste disposal, the intermittently high results need regulatory attention and resolution.

There may be other explanations of the intermittently high results. Testing is the avenue that must be undertaken to properly characterize and understand the sources and consequences of radioactivity at the landfill.

F. Evidence of radioactivity in the leachate test results is not rebutted by the fact that all waste entering the landfill has passed through entrance monitors

The leachate test results are *not* rebutted by the fact that waste entering the landfill has passed through radiation-detecting monitors. For this type of monitoring to be effective, landfills would need entrance monitors that cannot be "gamed" by methods such as *deliberately manipulating truckloads of radium-bearing waste* in order to reduce the amount of radon in the incoming load. "Gaming" may be done by simple methods such as aerating and/or flushing and/or suction (e.g., drawing a partial vacuum within a waste load by covering the load with a tarp and applying

suction from an ordinary shop-vac type of vacuum cleaner). DEC has not recognized that "gaming" is a problem and does not impose requirements to guard against "gamed" loads of waste entering landfills. Consequently, DEC's claims that wastes with high levels of radium and radon could not have passed through the gamma-detector entrance monitors at the Hakes landfill without triggering the monitors are unwarranted.

I identified this problem in my January 18, 2018 affidavit and showed how gamma-detector entrance monitors at Hakes and other landfills cannot reliably detect and prevent entry of waste loads carrying more than 25 pCi/g radium if precautions are not taken to prevent manipulation of loads of wastes entering landfills.

The issue of gamma-emission variability within waste loads that contain identical amounts of radium was identified as a study topic for the Pennsylvania DEP TENORM Study Report. In the scope of work for the report, the study topic was identified as follows:

> An assessment of secular equilibrium for the full uranium and thorium natural decay series as well as the Ra-226 and short-lived progeny sub-series, including the rapid buildup of radon and progeny in samples/waste streams impacted with radium. The evaluation of waste containing Ra-226 is subject to the buildup of radon gas and the other short-lived progeny of Ra-226, *complicating any decision made to transport or dispose of such materials based on an exposure rate survey of the container. The exposure rate is directly proportional to the degree of secular equilibrium and NOT proportional to the activity concentration of Ra-226* (remains the same as radon and other progeny buildup).

Pennsylvania Dept. of Environmental Protection (DEP), TENORM Study Scope of Work, p. 8, http://files.dep.state.pa.us/OilGas/BOGM/BOGMPortalFiles/RadiationProtection/TENORM-Study_SoW_04_03_2013_FINAL.pdf; emphasis added; word "NOT" capitalized in original.

The results of this assessment are presented and discussed in the Pennsylvania DEP TENORM Study Report, Rev. 1, May 2016. The results, while expressed for sludge or filter cake rather than drill cuttings, apply to any such radium-bearing waste. As stated in section 5.3 of the Report, "During handling and/or transport, the sludge or filter cake may be disturbed and some of the Rn gas may escape, *greatly reducing the gamma-emitting progeny* that follow Rn-222 in the natural decay series." (TENORM Study Report, Rev. 1, pp. 5-3 and 5-4, "Radon Ingrowth Within Filter Cake from WWTP to Landfills," emphasis added.) Modeling by Pennsylvania DEP examined the different gamma exposure rates measured 6 inches from the surface of the waste containers and found substantial variation in the gamma emission, depending on how much of the radon progeny remained in a given waste load along with its parent radium.[15]

[15] The Pennsylvania DEP TENORM Study Report, Rev. 1 (May 2016), refers to a six-fold difference, as compared to the 60-fold difference presented and discussed in my January 18, 2018 affidavit. The discrepancy is due to a minor error by the TENORM report authors in describing their own results. Their Figure 5.1, depicting the results of their MicroShield modeling, shows 3.94 for the lowest exposure rate and 24.1 for the highest exposure rate. The ratio of 24.1 to 3.94 is 6.12, which can be rounded off to "six times" or "six-fold." However, the same page of the report says "*Starting from zero Rn progeny* to full

In summary, the entrance monitors at Hakes and other landfills cannot reliably detect and prevent entry of waste loads carrying more than 25 pCi/g radium if precautions are not taken to prevent manipulation of loads of wastes entering landfills. Reliance on these monitors by DEC and CoPhysics is unfounded; hence there is no basis for DEC's argument in the FSEIS (at 26) that "there is no plausible manner in which such radon values in air or leachate can be caused by the drill cuttings present."

G. 1.05 million pCi/L radon in landfill gas exceeds radon levels found or reported in other landfills and landfill models – and also in uranium mines

It would be useful to assess Hakes landfill against either landfill models or actual landfills that have roughly comparable radon levels in landfill gas, but levels as high as 1 million pCi/L have not been found or reported for other landfills. Another potentially useful comparison would be to radon levels in uranium mines, even in older mines that took fewer protective measures, but here again the available data show substantially less than 1 million pCi/L radon in mine air. The lack of comparative examples in such subterranean spaces adds to the uncertainty about whether radium-bearing waste brought into Hakes has been limited to 25 pCi/g.

Available information on landfills provides little or no discussion or quantification of radon in landfill gas or its emission rate through the landfill cap.[16] Such information is likewise sparse in

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equilibrium after 21 days, the exposure rate measured 6 inches from the outside of the roll-off container increased six-fold. Based on the MicroShield® modeling results, there may be an increase of six times the gamma exposure rate measured 6 inches from the surface of the roll-off container during the first 21 days after a wastewater treatment sludge is generated. This is a theoretical curve and assumes all of the Rn is removed when the sludge is formed at time zero." (emphasis added) Contrary to the emphasized words in this quote, the TENORM report's graph (Fig. 5.1) and its interpretation of the modeling results fail to include the "zero Rn progeny" point. See the list of five data points at the top of page 5-4, starting with point "a" which is described as "0-day ingrowth (13.4 pCi/g of Ra-226 only)." In fact, this point is omitted from further consideration; only the last four data points are included in the graph (Fig. 5.1), despite what the authors say in the above-quoted words. Hence, the first of five data points, representing the gamma exposure rate from time zero (gamma from Ra-226 only, with no progeny) needs to be put into Fig. 5.1 before the full exposure trend can be seen. Just by eyeballing the existing curve – projecting it downward and to the left toward time zero – it is evident that the curve will intersect the vertical axis slightly above zero exposure rate. It can't be as low as zero exposure because that would mean that Ra-226 emits no gamma at all (untrue), but it may be as low as 0.5 or 0.4. The ratio of 24.1 to 0.5 is 48.2 (or 48-fold); the ratio of 24.1 to 0.4 is 60.25 (or 60-fold). While eyeballing like this won't provide a precise answer, it's obvious that the MicroShield results, if correctly reported, would show the full range of gamma-emission variation from a given quantity of radium as being close to the 60-fold value presented and discussed in my January 18, 2018 affidavit. And regardless of whether it's six-fold or 60-fold, this is an excessive and unacknowledged uncertainty in the landfill entrance monitoring procedure.

[16] For example, no substantive information on landfill radon is found on U.S. EPA websites such as https://www.epa.gov/landfills/industrial-and-construction-and-demolition-cd-landfills and https://www.epa.gov/lmop/basic-information-about-landfill-gas; NYS Dept. of Health website, https://www.health.ny.gov/environmental/outdoors/air/landfill_gas.htm; Illinois Dept. of Public Health

the available literature on landfill modeling studies. DEC's response to the Sierra Club comment letter relies substantially on two Argonne National Laboratory reports, by Smith et al. (1999)[17] and Harto et al. (2014),[18] both of which find acceptable human exposures from modeled landfills in which radium-bearing waste is limited to 50 pCi/g. These modeled results, which DEC considers strong evidence of minimal health impacts, beg the crucial question of whether radium-bearing waste brought into Hakes is as low as claimed (<25 pCi/g) or is in fact much higher. For the purpose of comparison, it is unfortunate that neither of these Argonne landfill models provides any quantitative details about radon flux through the modeled landfill cap, and neither model considers downwind radon transport and inhalation exposure to an offsite resident.[19] Fortunately, a 2012 study by Walter et al.[20] uses a roughly similar methodology, including the 50 pCi/g limit assumed by the Argonne authors, and also provides both landfill-gas and radon emission rates through a modeled 200 m x 200 m landfill cap.

For landfill-gas emission through the cap, Walter et al. show a rate of 0.2 m^3/sec, equivalent to roughly 8.5 moles/second of landfill-gas emission.[21] For radon emission through various cap systems of their modeled landfill, they show a range of about 6E+4 to 4E+6 pCi/sec, equivalent to roughly 10^{-13} to 10^{-15} moles/second of radon emission. In combination, these values indicate that the landfill gas emerging from the cap and vents of their modeled landfill *contains radon ranging from about 300 to about 20,000 pCi/L* on a steady-state basis, with the radon mole fraction being on the order of 10^{-14} to 10^{-16}. Such radon activities of 300 to 20,000 pCi/g are far less than 1 million pCi/L; hence, even allowing for some variation among the models by Smith,

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fact sheet, http://www.idph.state.il.us/envhealth/factsheets/landfillgas.htm; etc. *This is a serious omission if high levels of radon in landfill gas could indeed be produced by either local geology or typical C&D wastes, as DEC suggests may be happening at Hakes landfill*. Information on radon levels in landfill gas and radon emission rates through landfill caps is generally not included in otherwise useful literature on sites known to contain radium-bearing wastes (e.g., USGS, *Background Groundwater Quality, Review of 2012-14 Groundwater Data, and Potential Origin of Radium at the West Lake Landfill Site, St. Louis County, Missouri*, Dec. 17, 2014; revised June 10, 2015; "Missouri Department of Natural Resources to Transition Air Monitoring at Bridgeton Landfill Responsible Parties to Continue Air Monitoring," https://dnr.mo.gov/bridgeton/documents/airmonitoringstepdownannouncementwithcharts_000.pdf).

[17] K.P. Smith, D.L. Blunt, G.P. Williams, J.J. Arnish, M. Pfingston, J. Herbert, and R. Haffenden, *An Assessment of the Disposal of Petroleum Industry NORM in Nonhazardous Landfills*, DOE/BC/W-31-109-ENG-38-8, prepared by Argonne National Laboratory for U.S. Department of Energy, National Petroleum Technology Office, Tulsa, OK (1999).

[18] C.B. Harto, K.P. Smith, S. Kamboj, and J.J. Quinn, *Radiological Dose and Risk Assessment of Landfill Disposal of Technologically Enhanced Naturally Occurring Radioactive Materials (TENORM) in North Dakota*, ANL/EVS-14/13, prepared by Argonne National Laboratory (November 2014).

[19] Both focus more on *groundwater* pathways for radon exposure to an offsite resident. Thus, both acknowledge the possibility of radon inhalation by an offsite resident during showering, due to volatilization of radon from well water into the shower stall, but dismiss this inhalation risk and do not acknowledge or consider direct airborne impacts from radon flux through the landfill cap. See Smith et al., op. cit., at 34; Harto et al., op. cit., at 21.

[20] G.R. Walter, R.R. Benke, and D.A. Pickett, "Effect of biogas generation on radon emissions from landfills receiving radium-bearing waste from shale gas development," *Journal of the Air & Waste Management Association* **62**, 1040-1049 (2012).

[21] Hakes landfill-gas emission, mostly collected and flared, is a *roughly* similar rate. DSEIS, Appendix H.

Harto, Walter, and others, the radium-bearing waste which is limited to 50 pCi/g in these modeled landfills cannot account for 1 million pCi/L radon in landfill gas.

The inferred 1 million pCi/L in Hakes landfill gas may be either continual or intermittent, as discussed above. However, even if intermittent, there is no clear explanation of how an intermittently high level of about 1 million pCi/L could be generated and remain present in Hakes landfill gas for a long enough time to infuse the leachate with 270,000 pCi/L radon. This is yet another indication that measurement and modeling are needed to characterize the source and flux of radon within the Hakes landfill.

A corrective action report for the Blue Ridge Landfill in Kentucky shows two different modeled rates of radon emission through the cap of that landfill (0.0749 pCi/sec and 2.37 pCi/sec, per square meter of cap area), with the difference between these two values due to different modeled thicknesses of the radium-bearing waste layer and the overlying "clean" layer of municipal waste.[22] These radon emission rates correspond to about 2E-21 and 7E-20 moles/second per square meter of cap area, respectively. These emission rates are *roughly* comparable to the radon emission rates modeled by Walter et al.[23] The modeling done for the Blue Ridge Landfill assumed about 27 pCi/g radium in the radium-bearing waste layer, which is close to the 25 pCi/g nominal limit for Hakes, so it is unfortunate that the Blue Ridge corrective action report does not specify a landfill-gas emission rate for purposes of comparison.

Turning now to uranium mines in which both radium and radon are typically present at high levels, the U.S. National Academies' authoritative report, *Health Effects of Exposure to Radon*,[24] shows that mine radon levels are substantially lower than 1 million pCi/L, even in older mines that took fewer precautions to protect miners. Average radon activities for some of the highest-exposure uranium mines are reported as 1.6 WL or about 400 pCi/L (New Mexico cohort of miners), 4.9 WL or about 1230 pCi/L (Newfoundland cohort), 11.7 WL or about 2940 pCi/L (Colorado cohort), and 14.9 WL or about 3740 pCi/L (Port Radium cohort in the Northwest Territories of Canada).[25] *All of these radon levels are less than 1% of 1 million pCi/L*. Granted, these numbers don't express the higher and lower radon values that average out to the mean exposures, but another table from *Health Effects of Exposure to Radon* provides some of these higher values from the Ambrosia Lake uranium mines in New Mexico from the 1960-1961

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[22] Gradient Corp., *Corrective Action Plan (CAP) for the Blue Ridge Landfill, Estill County, Kentucky* (May 3, 2017), page 55 of Attachment A1 and page 20 of Attachment A2.

[23] The range of radon emission rates modeled by Walter et al., op. cit. (about 10^{-13} to 10^{-15} moles/second) is about 3E-18 to 4E-20 moles/second *per square meter of cap area*, thus *roughly* comparable to the modeled Blue Ridge Landfill emission rates.

[24] National Research Council, Committee on Health Risks of Exposure to Radon, *Health Effects of Exposure to Radon*, commonly called the "BEIR VI" report (Washington, DC: The National Academies Press, 1999).

[25] Id., Table D-12 (p. 270), where radon and radon-progeny exposure is reported as Mean Working Level (WL), weighted by person-years, including 5-year lag interval; with correlation between WL and pCi/L taken from Table ES-1 (p. 12). Note that exposures reported as "Weighted Mean WL" in Table D-12 are somewhat higher, sometimes by a factor of 2 or 3 or slightly more. See also pp. 254-269 for additional detail.

period, including measurements of 20 WL (about 5000 pCi/L) and 37 WL (about 9300 pCi/L).[26] But even these radon levels are less than 1% of 1 million pCi/L.

The above comparisons serve as a reminder that radon levels in enclosed underground spaces where radium is present, whether landfills or mines, are limited by such factors as the radium level (e.g., 25 pCi/g), the available space that the radon can occupy, and the pathway(s) that the radon can migrate along. It is instructive to consider a one-cubic-meter sealed container that contains, for example, compacted radium-bearing waste or soil with 25 pCi/g activity, 2 g/cm^3 bulk density, and 24.5% porosity. Let all the radium be Radium-226; the radon will then be Radon-222. The pore space can be considered occupied by air and/or landfill gas, and, after a few weeks, the pore space will also be occupied by an essentially constant level of radon that is at secular equilibrium with the radium in the sealed container. The total radium activity in the sealed container is 50 million pCi, and, after a few weeks, the total radon activity in the container will also be 50 million pCi. The volume of the pore space is 245 liters (i.e., 24.5% of one cubic meter), and the radon activity[27] in the air or landfill gas in the pore space is therefore 204,082 pCi/L. This radon level in the sealed container is about 20% of 1 million pCi/L. It will never exceed 204,082 pCi/L but will remain almost constant at that level, declining very slightly over time as its parent radium decays.

Further calculation with this example will show that the mole fraction of radon in the pore space is on the order of 10^{-13}, indicating that the radon atoms are dispersed among much larger numbers of molecules such as nitrogen, oxygen, and methane. Changing the radium activity in this example from 25 pCi/g to a higher or lower value would make a proportional change in the essentially constant radon level in the sealed container. Changing it to 125 pCi/g would increase the long-term radon level in the sealed container to about 1 million pCi/L. Changing it to a typical level for Steuben County soils would reduce the long-term radon level in the sealed container to much less than 200,000 pCi/g.

Alternatively, let the one-cubic-meter sealed container contain radium-bearing waste or soil with 25 pCi/g activity, 1.855 g/cm^3 bulk density, and 30% porosity. The total radium activity in the sealed container is 46.375 million pCi, and, after a few weeks, the total radon activity in the container will also be 46.375 million pCi. The volume of the pore space is 300 liters (i.e., 30% of one cubic meter), and the radon activity in the air or landfill gas in the pore space is therefore 154,583 pCi/L. The mole fraction of radon in the pore space is slightly smaller than in the previous example, but still on the order of 10^{-13}. Note that increasing the porosity and pore space does not increase the radon activity in pCi/L; it reduces it.

The interconnected pathways in underground spaces cannot be characterized with the simple type of calculation performed above for sealed one-cubic-meter containers. Characterization must usually be based on a combination of measurement and modeling – but it needs to be more than mere speculation about how radon might migrate. There are thermodynamic constraints on whether and how radon can become increasingly concentrated as it moves from a quasi-sealed

[26] Id., Table E-1 (p. 294), with correlation between WL and pCi/L again taken from Table ES-1 (p. 12).
[27] Assuming 1.54E+17 pCi/g specific activity of Radon-222.

environment (such as the above container or a tightly packed landfill space) into a series of pathways where it mixes – but is less likely to unmix! – with other gases. The very low mole fraction of radon is an important factor. Different gas solubilities may also play a role, as would need to be determined by the necessary combination of measurement and modeling. In the end, such characterization must explain not only the radon levels in landfill gas but also the intermittent process by which Hakes leachate has been infused with ~270,000 pCi/L radon. Such characterization, when done, will provide a meaningful basis for assessing health effects.

H. Could the leachate test results be measuring radiation coming from area geology?

While the possibility cannot be ruled out that the intermittently high radon comes mainly from naturally occurring onsite radium, the available evidence does not provide good support for this possibility. It is undisputed that many Steuben County homes have >4 pCi/L naturally occurring radon, but this fact does not translate into an explanation of the intermittently high radon at Hakes. The problems with attributing intermittently high radon to the local geology include 1) explaining how a sufficient amount of radon gas, or groundwater carrying dissolved radon, could migrate upward through the landfill liner to raise the radon concentration in Hakes leachate to ~270,000 pCi/L, at least intermittently, and 2) explaining how such upward migration through the liner could be so highly intermittent.

Before natural geology can be claimed as an explanation, it needs to be explained. Well-designed and properly executed testing would be needed to show that the intermittently high radon comes mainly from naturally occurring onsite radium. For example, while leakage through landfill liners to certainly known to exist,[28] it cannot be proffered as a vague, unquantified explanation of how radon could leak upward into leachate, especially because a) leachate typically flows *downward* through liner leaks, and b) liner leaks are recognized as serious problems in landfill operation and can't just be offered as a casual guess about how underlying radon might enter the leachate.

Furthermore, any finding that the intermittently high radon comes mainly from naturally occurring onsite radium would raise several new questions for regulators and policymakers.

It should be obvious that levels such as 1.05 million pCi/L radon in landfill gas, *if predominantly from radium-bearing waste*, warrant investigation of both the radium (how much? where in the landfill?) and the resulting radon, particularly the radon flow pathways and any offsite fate, transport, and associated risk. But even if the intermittently high radon is shown to be mainly from naturally occurring onsite radium, the above questions about radon flow pathways and offsite fate, transport, and associated risk do not automatically disappear! The landfill's role in concentrating the "natural" radon to such unusually high levels would need to be assessed and understood, and questions of onsite and downwind health impacts would still need to be assessed and resolved. Furthermore, if the intermittently high radon is mainly from naturally occurring

[28] Smith et al., op. cit., at 43 and 67.

onsite radium, an important question of site suitability arises for both the landfill and its proposed expansion.

As an example, the site would fail one of the U.S. Nuclear Regulatory Commission's disposal site suitability requirements for land disposal of radioactive wastes:

> The disposal site shall be capable of being characterized, modeled, analyzed and monitored.

10 CFR 61.50(a)(2).

This requirement, while not directly applicable to C&D landfills in New York, is eminently sensible. A site that undergoes wild swings in its naturally occurring radon cannot be reasonably characterized, modeled, analyzed, and monitored. Its unpredictable swings in natural radon would "mask" any migration of radium progeny and thwart any meaningful monitoring program. This principle is also expressed in the NYS siting requirements for radioactive waste disposal:

> The site must not be located where currently existing radioactive material, including but not limited to naturally occurring radioactive material, may mask the monitoring program.

6 NYCRR 382.21(a)(7).

6 NYCRR 363-7.1(a)(5)(iii), which *is* applicable to C&D landfills, requires that "Background radiation readings at the facility must be measured and recorded at least daily." Such a requirement would be meaningless if measurements of natural "background radiation" ranged from a few pCi/L to more than 1 million pCi/L at slightly different locations "at the facility."

Generally speaking, disposal-site performance needs to be understandable in some reasonable fashion. Wild swings in naturally occurring radon cannot reasonably be given a "free pass" that would exempt their causes and effects from being characterized and understood.

III. What might be the health effects of the levels of radioactivity shown?

A. What are the radiation dose, the applicable standard, and the associated risk?

The public health and occupational health risks associated with Hakes leachate, containing relatively low radium levels but intermittently very high levels of radon, have not been assessed and are currently unknown.[29] These risks need to be determined by a combination of testing and modeling, especially in view of the evidence that the landfill gas at least occasionally contains more than 1.05 million pCi/L radon. If there were either steady-state emissions or occasional

[29] See above and below for discussion of Argonne reports by Smith et al., op. cit., and Harto et al., op. cit.

"puffs" of such landfill gas, how often would downwind receptors be unduly exposed? What levels would landfill workers be exposed to? The risks cannot reasonably be assumed trivial, especially since landfill-gas emissions from the expanded landfill may triple from their current rate (see DSEIS, Appendix H, at 7). A publicly transparent program of air monitoring for radon and its progeny, combined with well-constructed air dispersion modeling, is needed. Dispersion modeling based on monitored pollution data is a well-known technique[30] for generating air-pollution maps and should be conducted at the Hakes landfill and surrounding area.[31]

Such testing and modeling are needed *regardless of whether such high levels of radon and its progeny are from radium-bearing waste or from naturally occurring onsite radium*. It is undisputed that naturally occurring radon causes exceedances of the 4 pCi/L health guidance level in many Steuben County homes, but a radon level such as 1.05 million pCi/L in landfill gas is so vastly different from 4 pCi/L that it requires testing and resolution. Does 1.05 million pCi/L landfill gas move offsite, and, if so, how much dilution and dispersion occur? How much do dilution and dispersion depend on weather conditions? These are among the questions that need to be answered to determine health impacts.

In addition, if further investigation of the disequilibrium between low radium and intermittently high radon in leachate shows substantially higher levels of radium in the landfill than currently acknowledged, then the *long-term health impacts* of such radium would need to be assessed and addressed.

When health effects are assessed, EPA's 4 pCi/L "action level" for indoor radon should *not* be used or adopted as the applicable radon exposure standard. The applicable exposure standard *must represent a level that has been recognized as reasonably safe*. Such a level is roughly an order of magnitude lower, i.e., about 0.4 or 0.5 pCi/L. EPA's 4 pCi/L action level is too high for this purpose; it corresponds to a Relative Risk of about 1.14 (i.e., about 14% excess risk)[32] and, according to EPA's estimates, about 7 in 1000 nonsmokers and about 62 in 1000 smokers may get lung cancer from lifetime exposure to radon at 4 pCi/L.[33] As enacted in U.S. law, the "national long-term goal of the United States with respect to radon levels in buildings is that the air within buildings in the United States should be as free of radon as the ambient air outside of

[30] Models such as ISCST3 and AERMOD typically represent pollutant emissions as point sources, but cf. S.G. Perry et al., "AERMOD: A Dispersion Model for Industrial Source Applications, Part II: Model Performance against 17 Field Study Databases," *Journal of Applied Meteorology* **44**, 694-708 (2005), at 703-04, for references to modeling involving multiple near-surface emission sources. Whether radon emission from Hakes landfill is best represented as a point source or multiple sources is unknown pending site-specific monitoring.

[31] DEC's SCREEN3 modeling in DSEIS Appendix H could provide a first step toward such modeling. This modeling was for hydrogen sulfide but would serve as a screening-level tool for radon if emission rates were either known or estimated over a range of possible values.

[32] National Research Council, BEIR VI, op. cit., 11, 17, 85, 115, etc.

[33] U.S. Agency for Toxic Substances and Disease Registry, *ATSDR Case Studies in Environmental Medicine: Radon Toxicity* (2010), https://www.atsdr.cdc.gov/csem/radon/radon.pdf, Fig. 2, at 31-32.

buildings,"[34] which is about 0.4 pCi/L.[35] Another standard in the same range, although not directly applicable, is the 0.5 pCi/L specified for emissions from the residual radioactive materials or tailings at inactive uranium processing sites. According to 40 CFR § 192.02(b)(2), "Control of residual radioactive materials and their listed constituents shall be designed to… [p]rovide reasonable assurance that releases of radon-222 from residual radioactive material to the atmosphere will not… [i]ncrease the annual average concentration of radon-222 in air at or above any location outside the disposal site by more than one-half picocurie per liter."

Walter et al., in their study of municipal solid waste landfills accepting up to 50 pCi/g radium-bearing waste, find that in some of the disposal scenarios they considered, "the radon flux from the landfill and off-site atmospheric activities exceed levels that would be allowed for radon emissions from uranium mill tailings" and that "...the simulated radon fluxes for the scenarios analyzed exceed the uranium mill tailings regulatory flux limits for the cases without a geomembrane cover, and exceed the off-site radon activity limit in all cases."[36] The similarity of the Walter et al. study to those cited by DEC (Smith et al. and Harto et al.), and the fact that the 50 pCi/g waste acceptance limit in all three is only twice the nominal 25 pCi/g limit at Hakes, serve as a reminder that health effects need site-specific investigation at Hakes. This is true regardless of whether the nominal 25 pCi/g limit at Hakes is shown to be credible or not.

B. Is the relationship between dose and risk *linear* down to very low doses, with *no threshold* below which there is no risk?

The U.S. National Academy of Sciences' Committees on the Biological Effects of Ionizing Radiation ("BEIR") have produced two comprehensive reports in recent decades; these are typically referred to as the BEIR V report and the BEIR VII report. I own a copy of the BEIR V report (it is a book of about 400 pages, entitled *Health Effects of Exposure to Low Levels of Ionizing Radiation*, published in 1990 by the National Academy Press). I have periodically consulted but do not own a hard copy of the BEIR VII report (*Health Risks from Exposure to Low Levels of Ionizing Radiation*, 2006, online at https://www.nap.edu/catalog/11340/health-risks-from-exposure-to-low-levels-of-ionizing-radiation) which provides a scientific update of BEIR V.[37] Both BEIR V and BEIR VII find that, *according to the preponderance of the scientific evidence*, there is a "linear, no-threshold" (LNT) relationship between dose and health risk, extending down to very low doses.[38] Both BEIR V and BEIR VII acknowledge the difficulty of proving this relationship at very low doses yet find that this LNT relationship, frequently called the LNT hypothesis, is the best fit of the available data.

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[34] 15 USC § 2661, Indoor Radon Abatement Act of 1988.
[35] U.S. EPA, *A Citizen's Guide to Radon*, EPA402/K-12/002 (2016), at 7.
[36] Walter et al., op. cit., at 1040 and 1048.
[37] Other BEIR Committees convened by the National Academies have produced more specialized reports such as National Research Council, BEIR VI, *Health Effects of Exposure to Radon*, op. cit.
[38] For example, BEIR V at 4 and 171-81; also Dr. Arthur C. Upton, pers. comm.; BEIR VII at 245-46 and discussion thereof in K.D. Crowley et al., *Radiation Research* **183**, 476-481 (2015).

I am not an expert in health physics but have been aware for the past few decades of ongoing scientific controversy about the LNT hypothesis. I have observed that scientists who challenge the LNT hypothesis often have a vested interest in nuclear technology, e.g., careers in a field such nuclear research, nuclear medicine, or the nuclear power industry.

This ongoing controversy should be recognized as relevant background information for interpreting the last part of the CoPhysics Report, where Dr. Rahon argues against the LNT hypothesis in his "Key Issue" #6, and where his Exhibit I is a published paper by Calabrese and O'Connor that is offered as a refutation of the LNT hypothesis. It should be noted that this Calabrese and O'Connor paper is not the "last word" on the topic, as both a response and a counter-response have been published.

The response is by K.D. Crowley et al., "Comments on Estimating Risks of Low Radiation Doses—A Critical Review of the BEIR VII Report and Its Use of the Linear No-Threshold (LNT) Hypothesis by Edward J. Calabrese and Michael K. O'Connor," *Radiation Research* **183**, 476-481 (2015). These authors quote from the BEIR VII report and discuss the BEIR VII Committee's reasoning for its conclusion:

> …the balance of scientific evidence at low doses tends to weigh in favor of a simple proportionate relationship between radiation dose and cancer risk.

BEIR VII at 246, quoted and discussed by Crowley et al. at 476.

The counter-response which continues to criticize the LNT hypothesis is by E.J. Calabrese and M.K. O'Connor, "Response to Comments on 'Estimating Risks of Low Radiation Doses—A Critical Review of the BEIR VII Report and Its Use of the Linear No-Threshold (LNT) Hypothesis'," *Radiation Research* **183**, 481-484 (2015).

Those assessing the scientific points at issue in the Hakes landfill expansion will need to draw their own conclusions about the merits of these differing views of the LNT hypothesis. My own best understanding is that K.D. Crowley et al. and the BEIR VII Committee exhibit the better scholarship on this subject, and that a) the evidence for understanding the dose-response relationship at low doses is difficult to assemble and interpret, yet b) when done carefully, the LNT hypothesis remains the best-supported scientific understanding of this relationship.

IV. DEC and CoPhysics have not provided substantive/credible responses to the Sierra Club comments

On a variety of points, DEC and CoPhysics have not provided substantive/credible responses. Most of these points have been discussed above in section II but are summarized in this section for each of the eight Sierra Club comments, listed below as A through H.

In general, DEC argues that the wastes accepted for disposal at the Hakes facility

> are not proposed to change. As explained in Section 2.4.9 of the DSEIS, these wastes have historically included drill cuttings and, therefore, the scope of the DSEIS was properly developed. Nevertheless, while the scope of the action before the Department remains the expansion of the landfill (including the borrow area) and does not include any approval related to a change in the acceptable waste streams, the Department has provided responses to all substantive comments related to radioactivity…

FSEIS at 14.

In fact, this claim that "the Department has provided responses to all substantive comments related to radioactivity" does not hold up to scrutiny. The responses provided by DEC and CoPhysics are not substantive and credible, as explained more fully below.

A. The DSEIS fails to evaluate the high levels of radioactivity shown in the landfill's leachate test results

The Sierra Club comment letter at 2-6 notes the contradiction between the landfill's own leachate test results (showing high levels of Lead-214 and Bismuth-214 in some of the samples) and the DSEIS claim that "at no time have any levels" of radioactivity in Hakes leachate "been detected that would indicate any radioactivity beyond those associated with background levels." The Sierra Club comment discusses the likely escape of radon from certain samples and the implications and significance of the high levels of Lead-214 and Bismuth-214 in certain other samples, with the latter result indicating about 270,000 pCi/L radon in the sample – and thus in the sampled leachate – at the time of collection, and further indicating about 1.05 million pCi/L radon in the air of the landfill, depending partly on whether or not the parent radium was immersed in leachate. The Sierra Club comment expressed a further concern about the reported discontinuation of Bismuth-214 and Lead-214 testing in leachate samples, the concern being that the loss of such data would undermine the ability of DEC and the public to understand and monitor the radionuclides in the landfill. Indeed, the comment recommended testing for a *greater* number of radionuclides rather than elimination of testing of the very radionuclides that have been observed in high levels in the leachate. Overall, by failing to address the likely source of the radioactivity demonstrated in the landfill's leachate test results, i.e., the Marcellus shale drill cuttings that have been accepted at the landfill since 2010, the DSEIS has not adequately assessed the issue of radioactivity in the landfill. The DSEIS has thus failed to provide a reasoned elaboration for why increasing the capacity of the landfill and allowing it to take more radioactive shale gas drilling wastes will not have an adverse effect on the environment and the health and safety of the people, animals and plants living near the landfill.

DEC's response (FSEIS at 18) refers to this Sierra Club comment as "B-1" and refers readers to its responses to comments B-10 and B-13.

DEC's response to comment B-10 (FSEIS at 21) does not address or acknowledge the issue raised in Sierra Club's comment about high levels of radioactivity shown in the landfill's leachate test results. DEC's first two points of response allege that categories of drilling wastes with high radioactivity would not be allowed for disposal at Hakes, and, furthermore, that "The

radiation detector would allow Hakes to prevent any wastes higher than 25 pCi/g from being accepted by the landfill." This last statement is incorrect; the entrance monitors (radiation detectors) cannot reliably prevent entry of waste loads exceeding 25 pCi/g. DEC's claims about waste categories that are not allowed for disposal at Hakes do not address or acknowledge the high levels of radioactivity that have been shown in the landfill's leachate test results. DEC refers to a truckload carrying radium-bearing waste (a radio-luminous ship deck marker) that tripped the Hakes entrance monitor in 2016. The description of this incident, while interesting with respect to wastes that were excluded from the landfill, is not informative in detail (it does not quantify either the amount of radium or the concentration of its progeny in the truckload), nor does it address or acknowledge the point raised in this comment about high levels of radioactivity shown in the landfill's leachate test results.

DEC's response to comment B-13 (FSEIS at 22-23), while it acknowledges the issue raised in Sierra Club's comment about high levels of radioactivity in the leachate test results, *provides no meaningful response*. DEC states that radium levels in the *leachate* are relatively low, which is generally not at issue.[39] DEC acknowledges that "Radon values can be inferred from the Pb-214 and Bi-214 gamma spectrometry results" but alleges "inaccuracies with results obtained for leachate and other liquid samples using the method that the comment is based on, which is EPA 901.1 gamma spectrometry." Such claims about "inaccuracies" are incorrect and misleading with respect to the intermittently high test results for Pb-214 and Bi-214 in Hakes leachate, as discussed above (in section II) in detail. Thus, no meaningful response has been provided to Sierra Club's comment about high levels of radioactivity shown in the landfill's leachate test results. DEC's claim that "any elevated radon and subsequent radon progeny in leachate is likely related to the local geologic sources" fails to recognize or address the distinction between radon levels ranging up to 1.05 million pCi/L in the landfill and the "indoor radon issues" in which household radon levels often exceed 4 pCi/L due to the natural geology of Steuben County. Any meaningful response by DEC would need to address the vast difference between 1.05 million pCi/L and 4 pCi/L (the former remains unexplained; the latter is readily explained by local geology), and would also need to address the extreme variability of the landfill radioactivity measurements (they're *intermittently* very high). DEC's response addresses neither of these. DEC's discussion of allowable radionuclide concentrations in sewer discharges is interesting but does not provide the type of evaluation indicated as necessary in the Sierra Club comment. The high radon levels, in particular, need to be – but have not been – evaluated with respect to their source and their impacts. Evaluation of their source would, in turn, address the fundamental issue of whether the landfill contains unacknowledged radioactive waste that substantially exceeds the landfill's nominal limit of 25 pCi/g.

DEC's response does not acknowledge or address the concern expressed in the Sierra Club comment about the reported discontinuation of Bismuth-214 and Lead-214 testing in leachate samples. As noted in the comment, the loss of such data would undermine the ability of DEC and the public to understand and monitor the radionuclides in the landfill. If any change is made, a *greater* number of radionuclides should be tested (including Lead-210). There would be no reasonable basis for eliminating the testing of the radionuclides that have been present in intermittently high levels in the leachate.

[39] The unknown radium levels in the *landfill* are a central issue, as discussed above. Test results indicate that radium levels in the *leachate* remain relatively low, as discussed above.

Part of DEC's response to comment B-9 (FSEIS at 20), proffered in response to a Concerned Citizens of Allegany County comment, is also noteworthy. DEC claims that "The two isotopes referred to in the comment are Pb-214 and Bi-214, which have half-lives of 26.9 and 19.9 minutes respectively. These isotopes will decay to stable elements before they could reach any potential receptors." The second sentence of this DEC claim is incorrect. The Pb-214 and Bi-214 radionuclides (isotopes) will in fact decay to the radionuclides Pb-210, Bi-210, and Po-210, which are widely recognized as health risks if ingested or inhaled,[40] before decaying to stable elements.

Part of DEC's response to comment B-11 (FSEIS at 22) is likewise noteworthy for its misleading statement that "Po-210 and Pb-210 break secular equilibrium, which in simple terms means that the resulting amount of these isotopes is a very small fraction of the initial Rn-222 value." This statement depends on what is meant by "amount" and on the time frame during which the health risk is considered. When Pb-210 and Po-210 are compared to their parent radon ("the initial Rn-222 value"), it is true that their activity in curies or pCi will be lower at the outset, but the fact remains that every Radon-222 atom will decay to Lead-210, Bismuth-210, and Polonium-210 before decaying to a stable Lead-206 atom.[41] Thus, compared to radon, the health risk window for Pb-210, Bi-210, and Po-210 is attenuated and prolonged, but not reduced overall. DEC's claim in the same response that "there is no realistic potential for buildup or accumulation resulting in impacts" depends entirely on fate, transport, and exposure scenarios, *which have not been addressed or assessed*.

The CoPhysics Report (at 18) argues 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)" and that *radium* levels in leachate are low. These claims miss the point of the *radon* levels that, as discussed above in section II, are intermittently very high in leachate and apparently in landfill gas as well, resulting in a host of unaddressed/unanswered questions about:

- the parent radium source (how much? where? is it "high and dry"? naturally occurring or from radium-bearing waste?),
- the fluctuating pathways and possible barriers responsible for the intermittent nature of the high radionuclide readings,
- the nature and magnitude of radon emission from the landfill, whether in puffs or a more constant plume, and
- impacts to downwind residents and landfill workers.

[40] For example, see https://www.ncbi.nlm.nih.gov/pubmed/4003271 (primarily about radon progeny in liquified petrolem gas [LPG]); https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2477690/ (Po-210 dose to Alexander Litvinenko); https://ehs.stanford.edu/reference/pb-210bi-210po210-radionuclide-fact-sheet (Stanford campus fact sheet). As usual with radioactivity and radioactive materials, the health risk is understood to be proportional to the exposure or dose.

[41] There is a negligible branching ratio from Pb-210 that may bypass Bi-210, etc.

B. The DSEIS fails to evaluate the adequacy of the landfill's entrance monitors

The Sierra Club comment letter at 6-7 notes that the DSEIS fails to evaluate the adequacy of the entrance monitors and points out the following claims that were made in the Hakes DSEIS:

> [a]t no time have any drill cuttings or other wastes from the oil and gas extraction industry set off the detector alarms at the Hakes Landfill. However, the alarms have proven to be effective in detecting several loads of solid waste that did not contain drill cuttings or other wastes from the oil and gas extraction industry, but potentially did contain radioactive wastes. This demonstrates the efficacy of the detection equipment.

As the Sierra Club comment letter points out, the logic of these claims in the DSEIS is faulty. With support from my January 2018 affidavit, the comment letter explains that the claimed efficacy of the detection equipment (the landfill's entrance monitors) in detecting radioactive waste entering the landfill is discredited by the landfill's leachate test results which show that there are significant levels of radium and radon in the landfill. My affidavit pointed out that truckloads carrying identical Radium-226 concentrations can have widely variable levels of gamma radioactivity measurable at the landfill entrance, depending on whether radium breakdown products have been allowed to escape from the load or not. This renders any "correlation" between the truckload sample analysis and the gamma radioactivity measurements meaningless unless the monitoring procedure at the landfill gate can quantify and control for the concentrations of radium progeny such as Lead-214 and Bismuth-214 in the load of waste at the time the truck enters the landfill gate.

DEC's main response (response B-2, FSEIS at 18) states that the landfill entrance monitors or "radiation portal monitors" are an established part of the landfill's permit requirements and "will continue to be operated to ensure compliance with any applicable waste acceptance limitations." This statement is merely conclusory and does not address the point at issue. DEC's response also claims that Radium-226 decaying within the matrix of drill cuttings "will retain most of the Rn-222 within the rock matrix, therefore the other progeny will remain within the matrix as well." As the basis for this claim, DEC refers to the behavior of "many natural materials including shale." This fails to address the point at issue, namely waste truckloads being *deliberately manipulated to remove radon gas* in order to pass through the entrance monitor while carrying substantially more than 25 pCi/g of radium-bearing waste. DEC's response also cites its 2015 High Volume Hydraulic Fracturing Response to Comments, page RTC-103 and its current Hakes FSEIS response to Comment B-10.

DEC's response to Comment B-10 (FSEIS at 21) does not acknowledge the point at issue, namely, that the entrance monitors detect only gamma radiation, most of which is from radium progeny rather than radium itself. DEC's first two points of response allege that categories of drilling wastes with high radioactivity would not be allowed for disposal at Hakes, and, furthermore, that "The radiation detector would allow Hakes to prevent any wastes higher than 25 pCi/g from being accepted by the landfill." This last statement is unsupported and merely conclusory. The claims about waste categories that are not allowed for disposal at Hakes do not address the efficacy of the entrance monitor. DEC's most informative response to comment B-

10 involves a truckload carrying a manufactured object containing radium (a radio-luminous ship deck marker) that tripped the Hakes entrance monitor in 2016. However, while interesting, DEC's description of this incident does not quantify either the amount of radium or the concentration of its progeny. It thus fails to address the point at issue here, namely, whether/how radium can be detected and properly quantified if accompanied by variable concentrations of its strongly gamma-emitting progeny.

DEC's 2015 High Volume Hydraulic Fracturing Response to Comments, p. RTC-103, defends gamma spectroscopy as a broadly recognized, efficient, and accurate method for quantifying radium in environmental samples. This is undisputed; it adds nothing to the point at issue here.

The CoPhysics Report (at 25-27, in its "Key Issue #3", and also at 17-18) recognizes the issue, namely, that the entrance monitors detect only gamma radiation, most of which is from radium progeny rather than radium itself, which "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." Id. at 25. Despite this recognition, the CoPhysics report claims that "The truck monitoring technique is highly proven and reliable" (id. at 17). The CoPhysics report's defense of the entrance monitors relies mainly on an exaggerated depiction of the issue ("the gaseous decay product [progeny] of radium, namely radon-222, emanates in vast amounts out of open-top truckloads," id. at 25) and on the professional experience of Dr. Rahon of CoPhysics:

> 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. Id.
>
> 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). Id. at 26.
>
> 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. Id. at 27.

All of these defenses of the efficacy of entrance monitors miss the point of *deliberately manipulated* truckloads of waste. The CoPhysics report also says that

> 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.

Id. at 26.

Again, these arguments about "not aerated and oven dried" miss the point of waste truckloads being *deliberately manipulated to remove radon* in order to pass through the landfill entrance monitor while carrying substantially more than 25 pCi/g of radium-bearing waste. As noted above, an efficient way to remove radon would not be aeration or oven-drying, but, instead, covering the waste load with a tarp and applying a partial vacuum with suction from a readily available shop-vac type of vacuum cleaner.

Another CoPhysics response on the entrance monitors involves the many truckloads of drilling waste that have *not* triggered the entrance monitors and the incorrect/misleading claim that "…Casella records show direct proof that the monitors work." Id. at 17. The alleged proof is that the entrance alarms at three Casella landfills *have* sounded a total of six times since being installed in 2010, with all six incidents traceable to nuclear medicine procedures or waste materials from such procedures. This information, if true,[42] is irrelevant to the entrance monitors' ability to detect and quantify radium. The sensitivity of the entrance monitors is not the main issue here. The issue is radium and whether/how it can be detected and properly quantified if accompanied by *widely variable concentrations* of its progeny which are strong gamma emitters.

CoPhysics also makes the following claims about the entrance monitors:

> 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. The 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....

CoPhysics Report at 17-18.

These claims are misleading and fail to address the relevant questions. Whether waste loads have triggered the alarms, and whether unauthorized drilling wastes have been kept out, is dependent on whether the radiation monitors at the gates are capable of detecting exceedances of the 25 pCi/g limit. This has been discussed above. Leachate monitoring can't "redundantly" confirm anything useful as long as the intermittently high radionuclide levels remain

[42] The CoPhysics description – stating that nuclear medicine isotopes rather than radium were involved in all six instances of entrance monitor alarms being triggered – is contradicted by DEC's description of the 2016 incident at Hakes where radium in a radio-luminous ship deck marker triggered the alarm.

unaddressed and unexplained. Most importantly, leachate monitoring can't confirm that there's no public health risk from drill-cutting disposal in Part 360 landfills until public-health (and occupational-health) risks from radon and its progeny have been satisfactorily identified and addressed.

C. The DSEIS fails to evaluate the presence of radon gas in the landfill's air emissions, gas collection system emissions, and emissions from flaring

The Sierra Club comment letter at 7-8 notes that the landfill is not testing for emissions of radon gas from the landfill surface or from the landfill's internal gas collection system; that radon is not flammable and will be released through the landfill's gas collection system during flaring of other landfill gases; that this concern about adverse effects on the environment and the health and safety of people, animals and plants living near the landfill is accentuated by the landfill leachate radionuclide test results which indicate that, at least at certain times, there is approximately 1.05 million pCi/liter of Radon-222 in the air within the landfill.

DEC's response (responses B-3a and B-3b, FSEIS at 18-19) argues that, while there is no standard for radon emissions from landfills, potential radon emissions from drilling-related wastes were part of the studies done by Argonne National Laboratory which showed that modeled radon exposures (assuming Radium-226 activity/concentrations of 50 pCi/g in the landfill waste mass) were below allowable limits. This fails to address the site-specific comment about ~1.05 million pCi/L radon in the air within the landfill. DEC's response thus fails to address the adverse effects of such radon, which cannot plausibly be assessed without testing and modeling. See also discussion above about the shortcomings of the Argonne studies by Smith et al. and Harto et al. DEC also claims that "Radioactive waste is not accepted at the landfill," but this begs the question of whether the Hakes landfill contains unacknowledged radioactive material or waste that substantially exceeds 25 pCi/L.

The CoPhysics Report (at 28-33, in its "Key Issue #5") acknowledges that some of the submitted comments express a concern about high levels of Radon-222, including radon in the air/landfill gas mixture that could have been as high as 1.05 million pCi/L:

> 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.

The CoPhysics Report responds by acknowledging the high levels of Bismuth-214 and Lead-214 in leachate samples collected from Hakes Cell #5 on 11/11/14 and Hakes Cell #8 on 6/6/17, and by recognizing that back-calculating (decay-correcting) from the analysis time to the time of sample collection would, if valid, imply an approximate Bismuth-214, Lead-214 and Radon-222 concentration of 275,000 pCi/L. However, the CoPhysics Report proceeds to make various arguments that have already been refuted in this memo (such as the alleged unreliability of EPA Method 901.1 for water analysis, the claim that "leachate sampling and analysis methods were never designed to be used for radon assessment," and the claim of "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"). The CoPhysics Report thereby reaches an incorrect conclusion that "the 275,000 pCi/L calculation cannot be relied upon as an accurate estimation of radon and progeny in the original on-site samples." After comparing "the 275,000 pCi/L calculation" to allowable sewer discharge levels (not directly relevant to the issue of 1.05 million pCi/L radon *in landfill gas*), the CoPhysics Report acknowledges that "The unusual results are certainly reason to conduct further investigation of the issue" but immediately follows this acknowledgment with the incorrect claim (refuted above) that Lead-210 analysis has already demonstrated "that the back-calculated radon result (275,000 pCi/L) is unreliable."

After further discussion of allowable releases to sewers, the CoPhysics Report returns briefly to radon in soil gas and notes that 63% of the homes in Steuben County "have natural radon concentrations exceeding the USEPA guideline." The CoPhysics Report then says (at 31-32) that

> …Part 380 further confirms that the radon at issue here is NORM, part of natural background and not subject to regulation. 6 NYCRR 380-l.2(c) & (e); 6 NYCRR 380-2.l(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-l.2(c) & (e); 6 NYCRR 380-2.l(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).

These comparisons between Part 380 and Parts 360-363, and between their respective requirements for TENORM and NORM, beg the fundamental issue raised in Sierra Club's comments, namely, whether the leachate test results combined with the unreliability of the entrance monitors indicate that the Hakes landfill contains unacknowledged TENORM and/or NORM that substantially exceeds 25 pCi/L.

The above-quoted text from the CoPhysics Report (at 31-32) also makes several claims that are entirely conclusory:

- "...landfills (including the Hakes Landfill) are not significant sources of downwind airborne radon"
- "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."

- "Relative to the radon exposure occurring in homes with or without mitigation systems, downwind radon exposures from landfills are extremely minor."

These assertions do not resolve the significant points at issue, especially since landfill-gas emissions from an expanded Hakes landfill may triple from their current rate, from ~250 scfm to ~750 scfm. (See DSEIS, Appendix H, at 7.) As indicated in the submitted comments, all of the above points need to be resolved by testing and modeling, not by mere assertion.

Finally, the CoPhysics Report returns to "potential impacts from radon's longer lived progeny, lead-210 and polonium-210" but does not address those impacts. Instead, the CoPhysics Report makes the incorrect argument (refuted above) that the "the 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."

The CoPhysics Report concludes its response to the issue of intermittently high radon in landfill gas as follows:

> 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.

This CoPhysics response to the issue of intermittently high radon in landfill gas is primarily a mixture of conclusory statements ("not to the extent suggested by the commentators" and "no cause and effect") and unsupported claims about the radon in question being "a natural occurrence." The more substantive CoPhysics claims that "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" and that "Natural radon would build up in these spaces" cannot explain high radon ranging up to ~1.05 million pCi/L. The accumulation of natural radon in air spaces is bounded by both theoretical limits and the empirical evidence from uranium mines, as discussed above in section II.G. It is well-known that radon builds up in air spaces at levels exceeding 4 pCi/L, but not at levels approaching 1 million pCi/L unless the surrounding soil and/or wastes contain far more than 25 pCi/g of radium.

Last but not least, it is important to recall the siting criteria for radioactive waste disposal which disallow disposal sites where existing conditions (in this case, high radon ranging up to ~1.05 million pCi/L) would mask any meaningful monitoring program. Meaningful monitoring should, for example, be able to distinguish whether Part 380 wastes are being improperly placed in Part 360-363 landfills. And even if further testing shows that C&D materials deposited in the landfill (brick, sheetrock, concrete block, wood ash, coal ash, etc.) are the main sources of radon within the landfill, such a finding could not reasonably be deemed acceptable without additional testing and modeling to determine fate, transport, and downwind impacts from radon levels that are either intermittently or continually as high as 1.05 million pCi/L.

D. The DSEIS fails to evaluate the possible presence of radium, radon and their breakdown products in the landfill's stormwater discharges, groundwater suppression system discharges or liner leakage discharges

The Sierra Club comment letter at 8-9 questions whether the DSEIS claim of "no groundwater contamination…" can be considered meaningful since neither the DSEIS nor the landfill's environmental monitoring protocols indicate any intention of testing for radium, radon or their breakdown products in ground- and surface water near the landfill. The comment notes that the positive declaration issued by DEC for the landfill expansion project acknowledged the potential for "significant impacts to groundwater requiring the design and construction of a landfill liner and leachate collection and leak detection systems," and acknowledged that the resulting construction and placement of waste in proximity to the existing water table requires that a groundwater suppression system be designed and installed. The Sierra Club comment then refers to the DSEIS which describes the landfill's groundwater and surface water monitoring program, states that the monitoring program is capable of detecting potential impacts to ground- and surface water before they can have a significant adverse impact on the environment, and claims that "To date, no groundwater contamination has been detected related to the operation of the lined cells." In light of the landfill's leachate test results, it is a serious omission for the DSEIS

not to address the adequacy of the landfill's ground- and surface water monitoring programs with respect to the radionuclides that are known to be present.

DEC's response (response B-4, FSEIS at 19) claims that:

> The acceptance of drill cuttings, the waste that prompted this comment, is not a new waste stream for the Hakes landfill. There is no change as part of this action related to waste types being accepted for disposal. Therefore, the type of waste being accepted and their potential impacts are outside of the scope of this EIS.
>
> The current Part 360 Hakes landfill permit already requires semi-annual leachate monitoring for radiological content, specifically for radium-226. If the landfill liner has a leak, it would be identified by the presence of Part 360 regulated landfill constituents in groundwater /or surface water samples which are obtained and analyzed quarterly in accordance with the EMP. Monitoring to date has not identified exceedances of groundwater standards for landfill constituents. If there was a buildup of NORM constituents in the landfill, it would be observed in leachate well before it was observed in the groundwater samples.
>
> Stormwater discharges from the facility do not pass through the waste mass, but are instead generated from waters diverted around the site, surface areas already completed with final cover, and other facility areas (e.g., roads). As such, it is not necessary to monitor stormwater runoff for radiological content. Such discharges are subject to the requirements of the SPDES Multi-Sector General Permit for Stormwater Discharges associated with Industrial Activity, Sector L (GP-0-17-004).

There are several problems with this response, starting with the above claim that "it is not necessary to monitor stormwater runoff for radiological content." This claim that monitoring "is not necessary" is contradicted by DEC's response B-7 (FSEIS at 20) which says that, "In the unlikely event of a leak in the liner system, leachate would ultimately migrate to the storm water system or groundwater collection system, which are both monitored."

Other problems include DEC's claim that any liner leak "would be identified by the presence of Part 360 regulated landfill constituents in groundwater /or surface water samples which are obtained and analyzed quarterly." This response does not address the portion of Sierra Club's comment about radiological groundwater contamination – and whether it can be detected, given the fact that "neither the DSEIS nor the landfill's environmental monitoring protocols indicate any intention of testing for radium, radon or their breakdown products in ground- and surface water near the landfill." If DEC's logic is that groundwater testing for chemical substances would reveal liner leakage even if no radionuclide testing is done, then this rationale should be clearly stated. Such rationale needs to include a quantitative sensitivity analysis to rule out the possibility that combined leakage of radionuclides and non-radioactive chemical substances may occur without exceeding thresholds for the tested chemicals. Radiological testing may be the more sensitive test, capable of detecting combined leakage at levels that may not exceed chemical test thresholds yet may be problematic with respect to radionuclide leakage.

DEC's claim that the acceptance of drill cuttings "is not a new waste stream for the Hakes landfill" does not address the concern that the 25 pCi/g waste acceptance limit may not have been honored. This concern, discussed at length above, is based partly on the intermittently high leachate results that remain unexplained. The concern originates from wastes that have already been landfilled but also applies to wastes that would be accommodated in the future by landfill expansion.

E. The DSEIS fails to evaluate the adequacy of the landfill's liner system and groundwater suppression system to protect against the radium, radon and their breakdown products present in the landfill from entering groundwater and surface water supplies adjoining the landfill

The Sierra Club comment letter at 9-10 refers to the DSEIS which states that the landfill's composite liner system is the main source of protection against groundwater contamination by the landfill but which fails to mention the liner's annual leakage rate, its expected life, and the risks of harmful exposures from its failure. The comment notes that C&D landfill liner systems are much less substantial than those used in landfills accepting low-level radioactive wastes, and that the DSEIS provides no risk analysis nor any evaluation of the types of environmental hazards the liner system can withstand or the circumstances in which the integrity of the liner system could fail. Given the numerous bodies of water and wetlands surrounding the landfill, and given the DSEIS's acknowledgment of landfill drainage to the Corning aquifer – the primary drinking water supply for the Corning-Painted Post metropolitan area – the DSEIS should have evaluated the adequacy of the landfill's liner system to protect these ground- and surface water resources from the radium, radon and their breakdown products present in the landfill.

Furthermore, the Sierra Club comment notes that, according to the DSEIS, Hakes is requesting a variance from the requirement in the solid waste regulations that the base of a landfill disposal cell be at least 10 feet above underlying bedrock. Given the reliance of the DSEIS on the effectiveness of a yet-to-be-constructed groundwater suppression system (which would nominally support the landfill's request that only a five foot of separation from bedrock be allowed), the Sierra Club comment expresses concern about the absence of any risk analysis and/or other evaluation in the DSEIS of the types of environmental hazards the groundwater suppression system can withstand or the circumstances in which the groundwater suppression system could fail. As noted in the comment, if the liner system or the groundwater suppression system were to fail, those failures may allow radium, radon and their breakdown products to be released from the landfill into surrounding water bodies and the environment. Such risks should have been, but were not, evaluated in the DSEIS.

DEC's response (response B-5, FSEIS at 19) simply refers readers to its previous B-4 response which is quoted above in relation to the preceding comment. There are several additional problems with this response with respect to the present Sierra Club comment, including DEC's failure to acknowledge Sierra Club's comments about:

- the liner's annual leakage rate which has not been identified (quantified) by DEC,
- the expected life of the liner,

- the risks of harmful exposures from liner failure,
- the lack of risk analysis or other evaluation of the types of environmental hazards the liner system can withstand or the circumstances in which the integrity of the liner system could fail,
- associated impacts to ground- and surface water resources, including wetlands, and
- the requested variance from the regulatory requirement that the base of a landfill disposal cell be at least 10 feet above underlying bedrock.

These issues have not been adequately addressed.

F. The DSEIS fails to evaluate the risk that opening up the landfill to tie-in the proposed expansion will create new pathways for radon and radium in the landfill to be released to the environment

The Sierra Club comment letter at 10 notes that the positive declaration issued by DEC for the landfill expansion project acknowledged that "[t]he project includes expansion of a solid waste management facility of large magnitude. It may result in the unearthing of C&D material as the new expansion is tied in with the existing facility. Bulk leachate storage and appropriate ongoing measures to prevent releases will be discussed." Despite this acknowledgment, there is no discussion in the DSEIS of the process by which the new expansion is proposed to be tied in with the existing landfill. DEC's comment notes that, although the process of opening up the existing landfill to tie in the new expansion will inevitably create additional pathways for radium, radon and their breakdown products in the landfill to be released into the environment, the DSEIS contains no risk analysis and/or other evaluation of the types of environmental exposures that may result from opening up the landfill for the tie-in process.

DEC's response (response B-6, FSEIS at 19-20) simply says that, "Based on an analysis performed by Argonne National Laboratory, even at radioactive concentrations of 50 pCi/g (twice the allowable acceptance limit set by the Department), potential public doses from all pathways were still below allowable dose limits," and also refers readers to its response B-3a.

The main problem with these DEC responses is their unfounded reliance on the Argonne studies by Smith et al. and Harto et al. See above discussion of the shortcomings of these two studies, including the fact that they do not acknowledge or consider direct airborne impacts from radon flux through the landfill cap.[43] See also the above-quoted findings by Walter et al. that in some of the relevant disposal scenarios, "the radon flux from the landfill and off-site atmospheric activities exceed levels that would be allowed for radon emissions from uranium mill tailings" and that "...the simulated radon fluxes for the scenarios analyzed exceed the uranium mill tailings regulatory flux limits for the cases without a geomembrane cover, and exceed the off-site radon activity limit in all cases."[44] Given the similarity of the Walter et al. study to the two Argonne studies, and given the fact that the 50 pCi/g waste acceptance limit in all three studies was only twice the nominal 25 pCi/g limit at Hakes, and especially given the various unanswered

[43] Smith et al., op. cit., at 34; Harto et al., op. cit., at 21.
[44] Walter et al., op. cit., at 1040 and 1048.

questions at Hakes, DEC's claim that "potential public doses from all pathways were still below allowable dose limits" cannot be considered protective and applicable. The unanswered questions at Hakes are very interrelated with radon pathways, which in turn are dependent on openings in the landfill cap. DEC's generalized response hasn't addressed such openings. They need to be addressed in a site-specific manner as part of the measurement-and-modeling-based assessment of radon pathways and health effects.

G. The DSEIS fails to evaluate the risk that the fires that have been occurring at the landfill have damaged the landfill's liner system, gas collection system or leachate collection system and have created or will create new pathways for radon and radium in the landfill to be released to the environment

The Sierra Club comment letter at 11 notes that:

> The DSEIS acknowledges that the landfill "has experienced both surface and subsurface fires." The DSEIS does not describe how many fires have occurred, in which cells the fires have occurred, how long the fires have lasted, or whether any fires are still burning within the landfill. The DSEIS does not evaluate whether the fires could damage or have already damaged the landfill liner system, gas collection system or leachate collection system and thereby create new pathways for radon and radium in the landfill to be released to the environment. Other than stating that the fires "could impact air resources by the release of smoke and other combustion products," the DSEIS contains no risk analysis and evaluation of the types of environmental exposures that could result from damages caused to damage the landfill liner, the gas collection system or the leachate collection system by the landfill fires….

DEC's response (response B-7, FSEIS at 20) simply says that, "In the unlikely event of a leak in the liner system, leachate would ultimately migrate to the storm water system or groundwater collection system, which are both monitored." This statement appears inconsistent with DEC's response B-4 (FSEIS at 19) which states that "it is not necessary to monitor stormwater runoff for radiological content" and is also misleading because leaks in the liner system are not "unlikely" (see overview of leaks in the Argonne report by Smith et al.[45] that is cited by DEC in the FSEIS). If the single composite liner system at the base of the Hakes landfill, consisting of a 60-mil textured HDPE geomembrane underlain by a compacted clay liner at least 2 feet thick, is substantially less prone to leakage than the liners described in the Argonne report by Smith et al. that DEC relies on, then DEC's response should address this in more specific and quantitative language than "unlikely."

DEC's response also refers readers to its responses C-1 through C-4 for information pertaining to landfill fires and the integrity of the landfill liner system, and to B-4 (already discussed in the preceding paragraph) for potential liner leaks. These referenced responses refer, in turn, to other

[45] Smith et al., op. cit., at 43 and 67.

responses such as G-5 for airborne resources impacts due to fires. Responses B-11 and B-15 are also cited for radiation-related issues (but their deficiencies have already been reviewed above). In these various responses, DEC acknowledges that landfill fires are "not an acceptable condition" under NYS solid waste management regulations, particularly 6 NYCRR § 215.2 and the conditions of a facility's Air State Facility permit. DEC refers to both surface and subsurface fires, saying that surface fires are promptly fought and extinguished, while subsurface fires (or "thermal oxidation") are monitored closely. If subsurface fires persist for more than a few days, DEC's response G-5 says that "injection wells/monitoring points are installed throughout the area. Water or leachate is introduced into the buried waste to cool, contain and extinguish any thermal oxidation." FSEIS at 43. DEC also says in response C-1 that:

> Once the temperature and the CO [carbon monoxide] return to safe levels for operation, the water or leachate introduction is suspended. Leachate is then collected and sent to a wastewater treatment plant. The integrity of the liner is evaluated based on the monitoring of the groundwater and stormwater at the site.

FSEIS at 31.

Whether the integrity of the liner can be evaluated based on groundwater and stormwater monitoring depends on two points noted above: **A**) Whether radiological testing is a more sensitive test than chemical analysis for a given mixture of radionuclides and non-radioactive substances, and thus more capable of detecting leakage through a damaged liner. This point has not been addressed but needs to be. **B**) Whether groundwater and stormwater are, or are not, tested for radionuclides. DEC's responses B-4 and B-7 appear inconsistent on this point.

DEC's response C-1 continues, and responds to part of Sierra Club's comment, as follows:

> At this point, there have been no leachate indicators leaving the site, indicating that no damage to the liner has occurred from a fire. This monitoring will continue during operation as outlined in the facility's Environmental Monitoring Plan.
>
> In 2014, concerns regarding potential damage to the liner system after a subsurface fire prompted an investigation into the liner system integrity. The landfill was excavated in an area where a subsurface fire was suspected of being in contact with the top of the leachate collection layer. The waste and leachate collection drainage layers were removed exposing the top of the geomembrane liner. There were no signs of distress (i.e., holes or obvious defects) in the geomembrane liner indicating that the leachate collection stone provided protection to the underlying layers. The rest of the isolated fires were elevated in the waste mass away from the landfill liner system.
>
> The landfill liner system and gas collection system are periodically monitored to evaluate their integrity. Monitoring includes the following activities;
>
> - The gas collection system is monitored quarterly for several parameters including; temperature, oxygen, carbon dioxide and methane. These parameters can provide early warning signs that conditions are changing that may impact the gas collection system. To

date, there have been no signs that the gas collection system has been impacted by the fires.

- The groundwater collection system beneath the base of the liner system is sampled and tested quarterly. The groundwater collection system analytical results would provide an early indication if the liner system was not operating effectively. To date, there has been no indication that the liner system has been compromised by the fires.

- The leachate collection system is cleaned annually. A high-pressure nozzle and hose are passed through each leachate pipe as water is used to flush and clean the pipes. There have been no blockages or signs that the pipes have been impacted by the fires.

Id. at 31-32.

One of the main points raised in the Sierra Club comment letter (that fires "have created or will create new pathways for radon and radium in the landfill to be released to the environment") remains unaddressed pending the measurement and monitoring that need to be done to characterize the landfill pathways through which radon moves. DEC's response G-5, while acknowledging the possibility of fires "which could impact air resources by the release of smoke and other combustion products," reaches a faulty conclusion that there would be "no significant release of radioactive air emissions due to fire" based on the logic that drill cuttings are not combustible. FSEIS at 42-43. The problem with this logic is the continually or intermittently high level of radon in Hakes landfill gas, ranging up to ~1 million pCi/L, which has not been addressed by DEC. While the methane present in landfill gas[46] will tend to burn and be consumed during a surface or subsurface landfill fire, the commingled radon in the landfill gas will continue through the combustion zone and be part of the visible smoke or any less visible plume of combustion products. The same is true, of course, for the routine flaring of landfill gas. Radon in the landfill gas continues through the flare and moves downwind with the combustion products.

H. The DSEIS fails to evaluate the health impacts of the landfill expansion project

The Sierra Club comment letter at 12-14 notes that, although the DSEIS states that "[a] major public concern regarding the construction or expansion of any solid waste facility is potential adverse impact on human health and the environment," it fails to provide any meaningful analysis of the potential adverse impact on human health and the environment of the landfill expansion project. In particular, it fails to evaluate human and environmental health risks from exposure to the levels of radioactivity shown by the leachate test data to be already present in the landfill or to evaluate the risks of the additional environmental exposures that would result from accepting additional levels of radioactive waste in the landfill. As a basis for comparison, the comment quotes New York's low-level radioactive waste disposal facility regulations which provide that "[c]oncentrations of radioactive material which may be released to the general

[46] The landfill gas contains at about ~31% methane, according to the DSEIS at 36.

environment in groundwater, surface water, air, soil, plants or animals must not result in an annual dose exceeding an equivalent of 25 millirems to the whole body, 75 millirems to the thyroid, and 25 millirems to any other organ of any member of the public. Releases of radioactivity in effluents to the general environment must be maintained as low as reasonably achievable." 6 NYCRR 382.11. The comment notes that the DSEIS provides no evaluation of potential exposures to radioactivity from radionuclides in the Hakes landfill. This omission is serious, as indicated by Dr. David Carpenter in the following portion of his affidavit that was quoted in the Sierra Club comment:

> [b]ased on the information provided to me and my knowledge of the human health effects arising from exposure to ionizing radiation, I have concluded that: (a) there are substantial and significant risks to human health posed by the current procedures used at the Hakes Landfill and approved by NYSDEC, (b) while the greatest threat to human health comes from inhalation of radon-222, other naturally occurring radioactive material (NORM) and the progeny of these elements pose significant threats to human health, and (c) inhalation is the route of exposure of greatest concern but other routes (ingestion, dermal absorption) are also possible.

For these reasons, the DSEIS should have provided an evaluation of potential exposures to radioactivity from the Hakes landfill and its proposed expansion. *The FSEIS does not remedy this defect*. Its argument on pages 55-56 that expansion would not increase the landfill's daily waste tonnages fails to acknowledge that landfill-gas emissions may triple from the current rate, from ~250 scfm to ~750 scfm (DSEIS, Appendix H, at 7), and misses the point that every additional amount of radium introduced to the landfill will add to the quantity already there.

The study by Walter et al. discussed above provides further support for the need for site-specific investigation of health effects, especially in view of the fact that the study's waste acceptance limit is only twice the nominal 25 pCi/g limit at Hakes. Walter et al., in their modeling of municipal solid waste landfills that accepted up to 50 pCi/g radium-bearing waste, found for some of their disposal scenarios that "the radon flux from the landfill and off-site atmospheric activities exceed levels that would be allowed for radon emissions from uranium mill tailings" and that "...the simulated radon fluxes for the scenarios analyzed exceed the uranium mill tailings regulatory flux limits for the cases without a geomembrane cover, and exceed the off-site radon activity limit in all cases."[47] Given these findings by Walter et al. in combination with the Hakes leachate test results, it is essential to characterize the landfill's radon impacts – and also its long-term radium impacts – or to engage NYS Dept. of Health to do so as a cooperating agency.

[47] Walter et al., op. cit., at 1040 and 1048.

Exhibit List

A) Excerpts from documents relating to EPA Method 901.1 uncertainty (with RV comments).

B) Excerpts from 6/6/17 Cell 8B leachate data.

C) D.E. McCurdy, J.R. Garbarino, and A.H. Mullin, *Interpreting and Reporting Radiological Water-Quality Data*, Techniques and Methods book 5, chapter B6, USGS Office of Water Quality, National Water Quality Laboratory (2008).