SUPREME COURT OF THE STATE OF NEW YORK
COUNTY OF STEUBEN

In the Matter of the Application of

SIERRA CLUB, CONCERNED CITIZENS OF ALLEGANY COUNTY, INC., PEOPLE FOR A HEALTHY ENVIRONMENT, INC., JOHN CULVER, AND BRIAN AND MARYALICE LITTLE,

Petitioners,

For a Judgment Pursuant to Article 78 of the Civil Practice Law and Rules,

–against–

NEW YORK STATE DEPARTMENT OF ENVIRONMENTAL CONSERVATION, BASIL SEGGOS, COMMISSIONER, TOWN OF CAMPBELL AND HAKES C&D DISPOSAL INC.,

Respondents.

AFFIDAVIT OF RAYMOND C. VAUGHAN IN SUPPORT OF THE AMENDED VERIFIED PETITION

Index No. E2019-0441CV

Hon. Patrick F. McAllister

State of New York,
County of Erie, ss.:

RAYMOND C. VAUGHAN, being duly sworn, deposes and says:

1. I am a Professional Geologist (NY license no. 258) and Environmental Scientist with a Ph.D. in Geology from SUNY Buffalo. I am very familiar with radioactive substances or "radionuclides," sometimes also called "radioisotopes." I am familiar with the physical and quantitative properties of these radionuclides and the alpha, beta, and gamma radiation they emit, including quantitative measures such as activity, specific activity, and half-life, and also including relationships such as secular equilibrium that may occur when a parent-progeny relationship exists among different radionuclides. My familiarity with such properties, measures, and relationships is based partly on my understanding and frequent use of numerical methods

and relationships in various fields of science and technology, partly on work relating to radionuclides that I performed during the twelve years I was employed as an Environmental Scientist at the NYS Attorney General's Office (2000-2012), partly on consulting work done for the Seneca Nation of Indians to review and interpret radiological test results (2016), and partly on technically-oriented volunteer work I have performed for several decades as a member of the Coalition on West Valley Nuclear Wastes (1978-2006) and also as a member of the West Valley Citizen Task Force (1997-present). I was appointed to the West Valley Citizen Task Force (CTF) by the U.S. Department of Energy and the New York State Energy Research and Development Administration (NYSERDA), and on one occasion in 2006 I testified on behalf of the West Valley CTF before the U.S. Nuclear Regulatory Commission in Rockville, MD. I have also spoken on behalf of the West Valley CTF at meetings such as the Council of State Governments/Blue Ribbon Commission public meeting in Boston (2011) and the National Transportation Stakeholders Forum meeting in Buffalo (2013).

2. I submit this affidavit in support of Petitioners' claims in the Amended Verified Petition regarding radioactivity[1] at the Hakes C&D Landfill in the Town of Campbell, Steuben County, New York (the "Hakes Landfill" or the "Landfill").

3. I have reviewed the Landfill's semi-annual Leachate Radionuclide Analytical Results from 2nd Quarter 2012 ("2Q2012") to 2nd Quarter 2019 ("2Q2019").[2] These reports

[1] Radioactivity describes a group of processes by which matter and energy are released from the nuclei of atoms as an alpha particle, a beta particle, or a gamma ray. The residual nucleus usually is transformed to a different element, and for alpha- and gamma-emitting nuclides, the energy of the emission(s) can be measured to identify the source radionuclide. See D.E. McCurdy, J.R. Garbarino, and A.H. Mullin, 2008, Interpreting and reporting radiological water-quality data: *U.S. Geological Survey Techniques and Methods,* book 5, chap. B6, at 1.

[2] The Leachate Radionuclide Analytical Results from 2Q2012 through 2Q2017 were attached to my 2018 Affidavit as Exhibits C through M. More recent Leachate Radionuclide Analytical Results from 4Q2017 through 2Q2019 are attached hereto as Exhibits A through D. An *additional* set of Leachate Radionuclide Analytical Results, from Hakes leachate samples collected 2/27/2018 and tested for Lead-210 and other radionuclides, is reported in the Final Supplemental Environmental Impact Statement for the Hakes Landfill expansion project dated December 5, 2018 (the "Hakes FSEIS"), Appendix 5, in Exhibit G of the CoPhysics report dated 5/16/2018.

summarize the results of tests for radionuclides in the Landfill's leachate conducted by laboratories selected by the operator of the landfill, Hakes C&D Disposal LLC ("HCDD"). The tests were performed on samples collected by the landfill, shipped to the laboratories and held approximately 21 days before testing. I have addressed my findings regarding the test results in a number of documents filed by the Petitioners in this case, as have two other expert witnesses, Dr. David Carpenter and Mr. Dustin May.[3] I summarize my findings in this affidavit.

4. What I found when I looked at the landfill's leachate test results is that several of the test results show very high levels of the radionuclides Lead-214 and Bismuth-214 in the tested samples, while at the same time showing consistently low levels of Radium-226.[4] Two of the tested samples contained ~6000 pCi/L of Lead-214 and Bismuth-214 at the time of sample testing.[5] Other Hakes leachate samples contained high but somewhat lesser levels. Twenty-two

[3] The documents filed by Petitioners discussing my findings regarding the leachate test results are: (1) My affidavit describing the evidence of high levels of radioactivity in the Hakes Landfill leachate test results dated January 18, 2018 (my "2018 Affidavit"), a copy of which is attached as Exhibit 1 to Exhibit B to the April 9, 2019 affidavit of Kathryn Bartholomew, (2) The affidavit by Dustin May, supervisor of the radiochemistry department of the State Hygienic Laboratory at the University of Iowa, the State of Iowa's public health laboratory, discussing the significance of results from the Hakes Landfill leachate test dated January 18, 2018 ("May Affidavit"), a copy of which is attached as Exhibit 2 to Exhibit B to the April 9, 2019 affidavit of Kathryn Bartholomew, (3) The affidavit by Dr. David Carpenter, Director of the Institute for Health and the Environment at the University at Albany and a former Director of the Wadsworth Center for Laboratories and Research of the New York State Department of Health, discussing the significance of results from the Hakes Landfill leachate test dated January 17, 2018 ("Carpenter Affidavit"), a copy of which is attached as Exhibit 3 to Exhibit B to the April 9, 2019 affidavit of Kathryn Bartholomew, (4) My presentation, *Unresolved Issues for Disposal of Radium-bearing Wastes at Hakes Landfill*, dated February 10, 2018 (my "2018 Presentation"), a copy of which is attached as Exhibit 4 to Exhibit B to the April 9, 2019 affidavit of Kathryn Bartholomew, (5) My memorandum, *Hakes FSEIS does not rebut the evidence presented by Sierra Club*, dated February 21, 2019 (my "2019 Memorandum"), a copy of which is attached to Exhibit D to the April 9, 2019 affidavit of Kathryn Bartholomew, and (6) My written comments at the June 27, 2019 legislative public hearing held by Respondent New York State Department of Environmental Conservation ("Respondent DEC") on the proposed Hakes Landfill permit modifications, a copy of which is attached to Exhibit A to the February 12, 2020 affidavit of Kathryn Bartholomew.

[4] The graphs on pp. 16-17 of my 2018 Affidavit cited in note 2 show the intermittently high levels of Lead-214 and Bismuth-214 in the Hakes leachate test results, ranging up to ~6000 pCi/L, and the substantially lower levels of Radium-226 in the leachate. Similar results, ranging up to ~1000 pCi/L, are seen in data from Chemung County landfill leachate tests. The Chemung landfill results show 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.

[5] Radioactivity is typically measured in curies (Ci) or smaller units such as millicuries (mCi) or picocuries (pCi). Picocuries per liter is abbreviated pCi/L and picocuries per gram is abbreviated pCi/g.

leachate samples tested for Lead-214 and Bismuth-214 between 2012 and mid-2018 had levels of these radionuclides that exceeded 100 pCi/L.[6] The 84 other leachate samples tested during this period had average levels of Lead-214 and Bismuth-214 of about 16 pCi/L. The six leachate samples with the highest tested levels of Lead-214 and Bismuth-214 were:

- ~6000 pCi/L in a sample of Cell #5 leachate collected 11/11/14
- ~6000 pCi/L in a sample of Cell #8B leachate collected 06/06/17
- ~3900 pCi/L in a sample of Cell #8B leachate collected 11/18/16
- ~2800 pCi/L in a sample of Cell #5 leachate collected 05/15/13
- ~2500 pCi/L in a sample of Cell #4 leachate collected 06/06/17
- ~1800 pCi/L in a sample of Cell #3 leachate collected 06/06/17

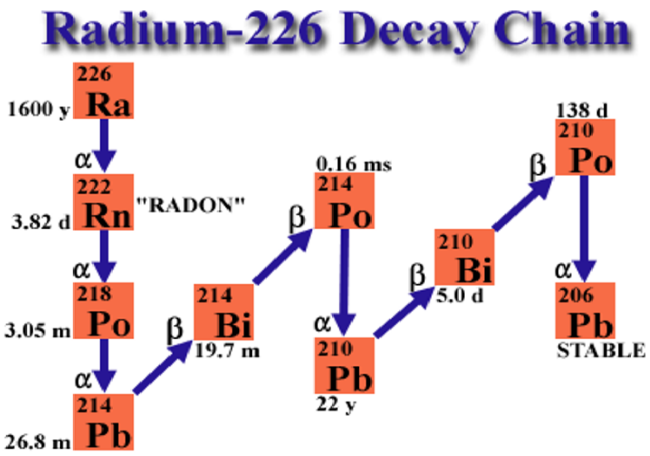
5. Comparing the consistently low levels of Radium-226 and the intermittently high levels of other radionuclides is significant because Radium-226, Radon-222, Lead-214, and Bismuth-214 are all part of a well-known radioactive decay chain that starts with Uranium-238. Each radionuclide in the decay chain is transformed at a predictable rate into its immediate decay product (the next lower member of the chain). This radioactive transformation process follows mathematical rules that have been recognized for more than a century, allowing useful comparisons among radionuclides and their concentrations in air, water, soil, leachate, and other substances.[7] The complete Uranium-238 decay chain is shown in the following diagram:

[6] 100 pCi/L is used here merely as an illustrative threshold which helps to illustrate the extreme range of leachate test results reported for Lead-214 and Bismuth-214; it has no particular scientific significance.

[7] One particularly useful set of mathematical relationships can be applied when adjacent radionuclides in the decay chain are in *equilibrium*, sometimes called secular equilibrium. However, there are other circumstances in which adjacent radionuclides in the decay chain may be in *disequilibrium* with each other, which often occurs, for example, when Radium-226 and its decay product Radon-222 become separated from each other. Such separation and disequilibrium are often a result of Radon-222 (a radioactive gas) drifting away from its parent Radium-226.

Uranium-238 (4.5 billion years)
↓
Thorium-234 (24 days)
↓
Protactinium-234m (1.2 minutes)
↓
Uranium-234 (240,000 years)
↓
Thorium-230 (77,000 years)
↓
Radium-226 (1,600 years)
↓
Radon-222 (3.8 days) (**GAS**)
↓
Polonium-218 (3.1 minutes)
↓
Lead-214 (27 minutes)
↓
Bismuth-214 (20 minutes)
↓
Polonium-214 (160 µsec)
↓
Lead-210 (22 years)
↓
Bismuth-210 (5.0 days)
↓
Polonium-210 (140 days)
↓
Lead-206 (stable)

Uranium-238 decay series (half-life in parentheses)



6. As shown in the diagram, Lead-214 and Bismuth-214 are created through the decay of Polonium-218 and Radon-222. Radon-222 is in turn created through the decay of Radium-226. Because Lead-214 and Bismuth-214 are decay products of Radium-226 and Radon-222, the presence of Lead-214 and Bismuth-214 in the leachate test samples shows that the parent radionuclides Radium-226 and Radon-222 are also present in the landfill, either within the leachate itself or in close enough proximity to the leachate that their decay products Lead-214 and Bismuth-214 end up in the leachate. For the reasons explained below, this is true even though the levels of Radium-226 in the leachate test results are low, typically less than about 4 pCi/L.

7. The half-life of each radionuclide is shown in the diagram. A radionuclide's half-life represents the average rate at which each of its atoms is transformed into an atom of the next member of the decay chain as a result of radioactive decay. For example, Radium-226 has a 1600-year half-life. This is the average rate at which an atom of Radium-226 is transformed into an atom of Radon-222. Radon-222 has a 3.82-day half-life. This is the average rate at which an

atom of Radon-222 is transformed into an atom of Polonium-218. Polonium-218 has a very short half-life of 3.1 minutes, which causes it to be transformed very quickly into an atom of Lead-214. Lead-214 has a short 27-minute half-life. The half-life of Bismuth-214 is 20 minutes. Bismuth-214 is transformed by radioactive decay into Polonium-214, whose extremely short half-life (160 microseconds) causes it to be transformed almost instantaneously into Lead-210. The Uranium-238 decay chain continues until it reaches Lead-206, which is a stable, non-radioactive substance. Radon-222 is the only element in the Uranium-238 decay chain that is a gas at normal temperatures.

8. Although the test results show only intermittently high levels of the radionuclides Lead-214 and Bismuth-214, the fact that these high levels are ever reached provides an understanding of radon levels in Hakes leachate ranging up to ~270,000 pCi/L and radon levels in landfill gas ranging up to ~1.05 million pCi/L.[8] See my 2019 Memorandum at 20-21 for details, particularly how the Radon-222 concentration in landfill gas is tied to the location of the parent Radium-226. The best understanding is that the landfill gas contains ~1.05 million pCi/L Radon-222 while the parent Radium-226 remains relatively "high and dry" in the landfill, immersed primarily in landfill gas rather than any hydrologically connected pool or stream of leachate, such that the ingrowth of Radon-222 occurs mainly within the landfill gas. In this case, Radon-222 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 the concentration gradient across the interface is sufficient to drive the migration, which means that the landfill gas at the interface must at least briefly contain more than about 1.05 million pCi/L Radon-222. This is the only way to carry enough Radon-222 into the leachate to reach ~270,000

[8] Throughout this affidavit, the words "radium" and "radon" refer to Radium-226 and Radon-222, respectively.

pCi/L dissolved Radon-222. This must be the case, given the contradictions explained in my 2019 Memorandum at 20-21 for the other alternative.

9. The two most likely explanations for why Lead-214 and Bismuth-214 are only intermittently high in the leachate test results are: (1) that some of the test samples were not properly sealed and radon gas was allowed to escape from the samples before testing, and (2) that the levels of radon gas contained in the landfill vary over time depending upon the opening and closing of various pathways of dispersal to the atmosphere.[9]

10. The fact that Lead-214 and Bismuth-214 have such short half-lives, 27 minutes and 20 minutes respectively, means that they are essentially gone from a sample within 5 hours if not they are not constantly regenerated by the decay of Radon-222. Any Lead-214 or Bismuth-214 measured in a sample, therefore, is less than about five hours old.

11. Even though the laboratories testing for the Hakes Landfill did not test the leachate samples for Radon-222, we can apply the scientific principle of secular equilibrium to show that if a sealed sample is more than five hours old, Radon-222 must be present in the sample at approximately the same levels as Lead-214 and Bismuth-214. Secular equilibrium is the situation in which the level or activity of a radionuclide in a sealed container matches the activity of its decay product (because its production rate due to decay of its parent radionuclide is equal to its decay rate), causing both radionuclides to decay at the same exponential rate.[10]

---

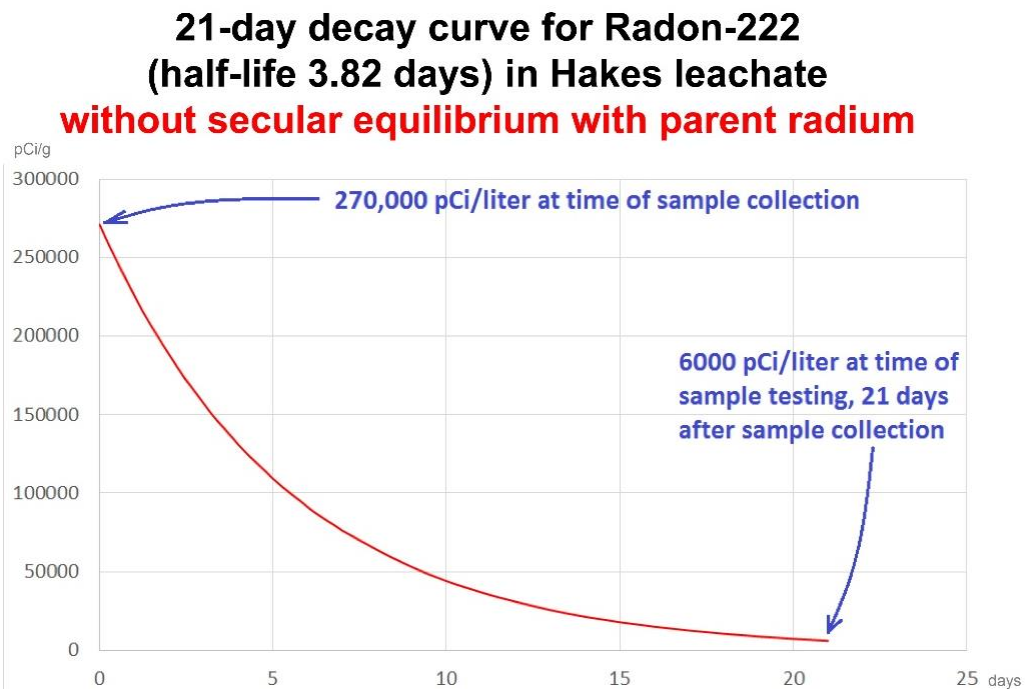
[9] Since radon is a gas, a likely explanation of low Lead-214 and Bismuth-214 levels in some of the samples at the time of testing is that radon leaked out of some of the sample containers during the sample holding period of about 21 days or during the testing process itself. This possibility is discussed in the affidavit of Dustin May, cited in Footnote 2 and attached to the April 9, 2019 affidavit of Kathryn Bartholomew.

[10] Secular equilibrium and radioactive decay are illustrated graphically in slides 15-20 of my 2018 Presentation, one of which is reproduced here. The radioactive decay law is expressed as Equation (1) in my 2019 Memorandum at 15. Good overviews of secular equilibrium and radioactive decay can be found online at www.nrc.gov/docs/ML1122/ML11227A233.pdf (attached to my 2018 Affidavit as Exhibit Q) and https://www.nrc.gov/docs/ML1126/ML11262A156.pdf, and in books such as G.R. Choppin, *Nuclei and Radioactivity* (New York: W.A. Benjamin, Inc., 1964).

Given the levels of about 6000 pCi/L Lead-214 and Bismuth-214 in two of the leachate samples at the time of sample testing, and given the fact those samples had been sealed for much longer than the 5 hours needed to reach equilibrium, the principle of secular equilibrium tells us that ~6000 pCi/L of Radon-222 was also present in those samples at the time of testing.

12. The Hakes test samples were held for 21 days between sample collection and testing. The scientific principle of secular equilibrium shows that if a sealed sample is more than about 21 days old, and if Radium-226 is initially present and its decay products are initially absent at the beginning of the 21-day period, then at the end of the 21-day period Radon-222 and its decay products Lead-214 and Bismuth-214 must be present in the sample at essentially the same level as Radium-226. This is clearly not the case in the samples whose test results show an extreme mismatch (*disequilibrium*) between only a few pCi/L of Radium-226 and up to ~6000 pCi/L of Lead-214 and Bismuth-214 (and likewise ~6000 pCi/L of Radon-222, as noted in preceding paragraph). For these samples, in order to have ~6000 pCi/L of Radon-222 present in the sample after 21 days, *and in view of the test results which show far too little radium in the sample to replenish radon at ~6000 pCi/L*, the amount of Radon-222 present in the sample at the time of collection must have been much higher. This follows from the well-known radioactive decay law, as expressed as Equation (1) in my 2019 Memorandum at 15. This shows that, in order to have 6000 pCi/L of Radon-222 present in a sample 21 days after collection, the amount of Radon-222 present in the sample at the time of collection would have been ~270,000 pCi/L. The following diagram from my Feb. 10, 2018 presentation[11] graphs the exponential rate of Radon-222 decay over time.

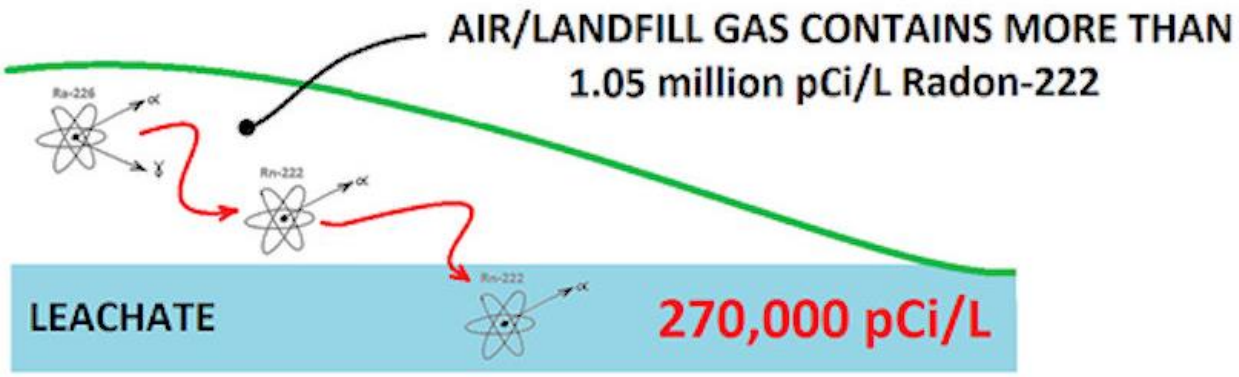
[11] Cited in footnote 2 above.



13. In order to have 270,000 pCi/L of Radon-222 dissolved in the landfill leachate, there must also be Radon-222 present in the air of the landfill. Radon is a radioactive gas which, like other gases, can mix with air and can also dissolve in water and water-based mixtures such as leachate. Radon's equilibrium concentration (or activity) in air is related to its concentration (or activity) in water through known principles of physical chemistry such as the partition coefficient and Henry's Law.[12] Air and water provide good approximations for landfill gas and water-based mixtures such as leachate.

14. Using the scientific principles of the partition coefficient and Henry's Law, the presence of ~270,000 pCi/L of Radon-222 dissolved in the landfill leachate indicates a Radon-222 level ranging up to ~1.05 million pCi/L of Radon-222 in landfill gas, as illustrated by the following diagram from my Feb. 10, 2018 presentation:

[12] See esp. my 2018 Affidavit at 25 and sources cited therein.



15. See my 2019 Memorandum at 20-21 and my 2018 Affidavit at 25-27 for further information, particularly details of how the Radon-222 concentration in landfill gas is tied to the location of the parent Radium-226. The best understanding is that the landfill gas contains ~1.05 million pCi/L Radon-222 while the parent Radium-226 remains relatively "high and dry" in the landfill, as illustrated above..

16. 1.05 million pCi/L of Radon-222 is an extremely high level of radon, more than 100 times higher than the levels reported in uranium mines.[13] If a known radium source such as a uranium mine[14] produces only about 10,000 pCi/L of radon in the air within the mine, how can a landfill that accepts no more than 25 pCi/g radium in its wastes produce up to 1.05 million pCi/L of radon in its landfill gas? This type if comparison is no substitute for actual testing, yet it serves as a warning or caveat that the claimed low level of radium in the Hakes landfill waste can't be reconciled with the intermittently high radon levels indicated by the landfill's own leachate test results.

17. As another illustration that 1.05 million pCi/L of Radon-222 is an extremely high

[13] See my 2019 Memorandum at 26-27, showing radon levels no higher than about 10,000 pCi/L reported in uranium mines. This is only about 1% of 1.05 million pCi/L.

[14] For example, in the Hakes FSEIS, Appendix 5, see the 5/16/2018 CoPhysics report at 13 for the range of 150 to more than 1000 pCi/g radium in uranium ore.

level, consider EPA's recommendation that action be taken at a level of 4 pCi/L inside a house to reduce exposure to radon gas.[15] In the Town of Campbell, residential radon levels are reported to be 15.37 pCi/L average (65.30 pCi/L maximum) for basements and 4.79 pCi/L average (73.90 pCi/L maximum) for 1st-floor living spaces.[16] All of these levels are a tiny fraction of 1.05 million pCi/L.

18. As described above, Radon-222 does not exist in isolation; it must be continually replenished by nearby Radium-226. Because Radon-222 is a gas, it is subject to principles such as solubility and partitioning that are well-known in physical chemistry.

19. I have explained that there is secular equilibrium among Radon-222, Lead-214, and Bismuth-214 whenever these three radionuclides remain in a sealed container for more than about 5 hours, and that there is disequilibrium in the leachate test results between these three radionuclides and Radium-226. The leachate test results show minimal Radium-226 available in samples to replenish Radon-222 as it decays. There is often some amount of disequilibrium between Radium-226 and Radon-222 because Radon-222 is a gas that can drift away from its parent Radium-226. Often Radon-222 is depleted relative to Radium-226 because some of it has drifted away. The opposite is true in some of the Hakes leachate samples, where Radon-222 is extremely elevated relative to Radium-226.

20. Because Radon 222 is a breakdown or decay product of Radium-226, the presence of such high levels of Radon-222 in the air of the landfill shows that Radium-226 is present in the landfill and is generating the Radon-222. Although the exact location and amount of the Radium-226 cannot be known without further testing, its location must be close enough to

[15] For example, see https://www.epa.gov/radon/what-epas-action-level-radon-and-what-does-it-mean.

[16] From https://www.health.ny.gov/environmental/radiological/radon/towns.htm, checked 1/18/20, showing results as of October 2019 for 35 basement-level and 45 1st-floor measurements from homes in Town of Campbell.

the leachate, and its concentration must be high enough, to supply the high levels of Radon-222 breakdown products – Lead-214 and Bismuth-214 – found in the leachate. This means that the Radium-226 must be located in the landfill.

21. Although high levels of Radium-226 have not been shown directly in the Hakes leachate test results, this does not mean that radium is not present in the landfill. It most likely means that the radium is in a location high enough in the landfill that it is not exposed to water or landfill leachate, i.e., in a high and dry location. Even in a high and dry location, Radium-226 is constantly breaking down or decaying into Radon-222. Because Radon-222 is a water-soluble gas, it can migrate through the pores of the landfill and become dissolved in the leachate. Radium-226, which is not a gas, can only migrate by direct physical movement or by being dissolved in water or leachate.

22. The presence of a sufficient quantity of radium in the landfill has not been acknowledged or explained by Respondents. In fact, in their documents responding to Petitioners' comments setting forth the results of my findings,[17] Respondents attempt to dismiss the significance of the evidence I have presented. They fail to do so. I discuss Respondents' arguments and the reasons these arguments do not rebut Petitioners' evidence in the sections below.

23. Furthermore, it is evident that Respondents have not engaged in simple testing of the landfill's gas collection system to verify or disprove Petitioners' calculations regarding the

[17] These documents include the Final Supplemental Environmental Impact Statement for the Hakes Landfill expansion project dated December 5, 2018 (the "Hakes FSEIS"), the report by CoPhysics Corporation, dated May 16, 2018 (the "CoPhysics Report) appended to the Hakes FSEIS, the two findings statements issued by the Town of Campbell, one by the Town Planning Board on January 16, 2019 and one by the Town Board on March 11, 2019 (the "Town Findings Statements"), the finding statement issued by DEC on December 19, 2019 (the "DEC Findings Statement"), and the permit responsiveness summary issued by DEC on December 19, 2019 (the "Responsiveness Summary").

presence of radon in the landfill.

Testing Methodologies

24. One of the challenges offered by Respondents to Petitioners' evidence is an objection to the test methodology for measuring Lead-214 and Bismuth-214 in the landfill leachate, EPA Method 901.1. This is an odd objection because EPA Method 901.1 was the test methodology prescribed by the landfill's facility manual for use in conducting gamma testing of radionuclides in the landfill leachate in from 2012 until mid-2018.

25. EPA Method 901.1, developed for measuring gamma emitting radionuclides in drinking water, measures gamma emissions by means of a gamma spectrometer.[18] The fact that the test was used on Hakes landfill leachate rather than drinking water would result in negligible gamma reduction due to the suspended solids in the leachate. Thus, EPA Method 901.1 is a valid method for testing the levels of Lead-214 and Bismuth-214 in landfill leachate. See my 2019 Memorandum at 8-12 for details.

26. The fact that the landfill's gamma spectroscopy results showed close correspondence between the levels of Lead-214 and Bismuth-214 in the leachate (i.e., when the levels of Lead-214 were high, the levels of Bismuth-214 were similarly high, and when the levels of Lead-214 were low, the levels of Bismuth-214 were likewise low) helps demonstrate the validity of using EPA Method 901.1 for testing Hakes leachate samples. A defective test method would not produce such consistently well-matched results for Lead-214 and Bismuth-214 over the wide range of test results reported for the 106 samples of leachate that were tested on behalf of the landfill operator between 2012 and mid-2018.

27. DEC's claim that "this analytical method [Method 901.1] was originally designed

[18] https://www.epa.gov/sites/production/files/2015-06/documents/epa-901.1.pdf

for soil analysis and the use of it for water analysis results in unacceptably high uncertainties"[19] is not true. As explained in my 2019 Memorandum, Method 901.1 is an analysis method for water.[20]

28. DEC's claim about "unacceptably high uncertainties" is misleading. As I explain in my 2019 Memorandum, the assertion that there is "uncertainty" regarding Method 901.1 boils down to a simple fact that is well-known to testing labs and those who submit samples and review the results.[21] 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 MDC, then Method 901.1 does not provide reliable or useful results because, in effect, "noise" overwhelms the signal. 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 the "plus or minus" value that accompanies many different types of measures, representing the outer limits of the likely true value of the measurement. All radionuclide test results are reported with "plus or minus" figures. For example, the leachate test results for Lead-214 and Bismuth-214 in one of the June 2017 samples showed levels for both in the range of 6000 pCi/L. This is well above the MDC which is in the range of 70-84 pCi/L. Uncertainties for the high Lead-214 and Bismuth-214 test results are generally higher than for the low Lead-214 or Bismuth-214 results. This is entirely to be expected.[22] There is thus no basis for rejecting the Lead-214 and Bismuth-214 results as

[19] Responsiveness Summary at 6.

[20] See my 2019 Memorandum at 12.

[21] Id. at 8-12.

[22] See Exhibit B to my 2019 Memorandum for the actual numbers reported for the Hakes leachate test results.

"uncertain." A standard test practice should not be distorted into assertions about the "uncertainty" of Method 901.1.

29. In mid-2018 – after Petitioners filed their lawsuit challenging DEC's decision not to include radioactivity issues in the final scoping document for the Hakes landfill expansion draft supplemental environmental impact statement (DSEIS) and filed the affidavits of myself, Dr. David Carpenter, and Mr. Dustin May raising concerns about intermittently high levels of Lead-214 and Bismuth-214 in the leachate test results – DEC revised the landfill's testing requirements and eliminated the requirement for gamma testing of the landfill leachate. In correspondence with the landfill, DEC specifically removed the requirement to use EPA Test Method 901.1.[23] The elimination of EPA Test Method 901.1 eliminated the requirement for testing of Lead-214 and Bismuth-214. At no time has the landfill been required to test the landfill leachate for Radon-222.

30. In the Responsiveness Summary, DEC states that "The Department has chosen not to use EPA 901.1 to analyze for radium in leachate…"[24] In fact, DEC eliminated EPA Method 901.1 testing not only for radium but also for its decay products Lead-214 and Bismuth-214. DEC's testing protocol for Hakes leachate now relies on other tests for Radium-226 (using EPA Method 903.1), Radium-228 (using EPA Method 904.0), and Total Uranium (using EPA Method 908.0). Testing of the Radium-226 breakdown radionuclides such as Lead-214 and Bismuth-214 using gamma spectroscopy pursuant to EPA Method 901.1 has been abandoned. DEC has thus lost the ability to detect radium decay products in the Hakes landfill leachate, thereby creating a "blind spot" in radiological monitoring at the Hakes landfill. In effect, DEC is

[23] See Exhibit E.

[24] Responsiveness Summary at 6.

"shooting the messenger."

Equilibrium and Radioactive Decay

31. DEC's claims in the Responsiveness Summary that there are "potentially erroneous assumptions of equilibrium" and "imbalances in the usual equilibrium assumptions" are frivolous and misleading.[25] Contrary to what DEC suggests, it is entirely obvious that there is severe disequilibrium between radium and its decay products in the Hakes leachate samples that show low levels of Radium-226 and high levels of Lead-214 and Bismuth-214 in the leachate test results. Thus, there is no rational basis for DEC to suggest that "equilibrium assumptions" are relevant to this disequilibrium between radium and its decay products in the sealed sample containers. However, among the decay products Radon-222, Lead-214, and Bismuth-214 in the sealed sample containers, equilibrium does exist and must be assumed to occur. There is no basis for suggesting "imbalances" or asserting "potentially erroneous" assumptions of equilibrium for the three decay products that must inevitably be at equilibrium with one another after ~21 days in a sealed sample jar.

32. There is no basis for DEC's claim that the scientific principles I describe in my 2018 Affidavit and summarize above "could only have been speculatively back-calculated using several assumptions utilizing the Lead-214 and Bismuth-214 values shown to exist in the Landfill leachate."[26] The exponential decay process I describe can be, and has been, called back-calculation. Regardless of the name, it is the well-known process of radioactive decay that has been recognized and understood for more than 100 years. The decay curve is defined mathematically by Equation (1) in my 2019 Memorandum at 15, and its error bounds are defined

[25] Id. at 6-7.

[26] Id. at 7.

there by Equation (2). The curve (the decay process) follows the same mathematical definition regardless of whether the decay process in a sealed container is being back-calculated into the past or forward-calculated into the future. *Quite simply, back-calculation is an entirely valid and well-understood process.* It is explained in detail in my 2019 Memorandum.[27]

33. Accordingly, there is no basis for DEC's claim[28] that these radon concentrations are "speculatively" back-calculated. It is clear from dictionary definitions[29] and DEC's own SEQR Handbook[30] that the concentrations of radon in the leachate and landfill gas are not "speculatively" back-calculated. As described above, these radon values are supported by reasonable observations and data from the landfill operator's own testing program, and by firm evidence, demonstrable facts, knowledge, and fact-based reasoning based on well-established scientific principles. They are not based on guesses, conjecture, contemplation, or purely abstract or theoretical reasoning.

34. In summary, back-calculation is valid within the error bounds set forth in my 2019 Memorandum at 15-19. Intermittently high levels of Lead-214 and Bismuth-214 in the landfill's leachate test results provide clear evidence of high levels of Radon-222 in the leachate (ranging up to ~270,000 pCi/L) at the time of sample collection. While the leachate contains comparatively low levels of the parent Radium-226, there must be more nearby. Substantial amounts of Radium-226 must exist and continually decay in close proximity to the leachate in

[27] Wherein the text and tables on pp. 12-19 walk the reader through the mathematical details and error bounds.

[28] Responsiveness Summary at 7.

[29] Typical dictionary definitions of "speculative" are: Based on a guess and not on information; based on conjecture rather than knowledge; based on conjecture without firm evidence; based on guesses or ideas about what might happen or be true rather than on facts; theoretical rather than demonstrable; theoretical, not practical; based on contemplation, conjecture, or abstract reasoning.

[30] See the current version of DEC's SEQR Handbook (Draft Revised 4th edition, 2019, https://www.dec.ny.gov/docs/permits_ej_operations_pdf/dseqrhandbook.pdf) at 145, defining speculative comments as assertions that are not supported by reasonable observations or data.

order to produce the aforementioned high levels of Radon-222 in the leachate.

35. High levels of Radon-222 in landfill leachate must necessarily be related and relatable to Radon-222 and Radium-226 elsewhere in the landfill, including in the landfill gas. This is true because Radon-222 must be continually replenished by nearby Radium-226.

36. As a gas, Radon-222 is subject to principles such as solubility and partitioning that are well-known in physical chemistry. The well-known and well-documented principle of the partitioning of a gas between water and air, quantified by the Bunsen coefficient or the partition coefficient, has been known for more than 100 years.[31] As outlined in my 2018 Affidavit at 25, water that contains ~270,000 pCi/L dissolved Radon-222 is at equilibrium with an overlying air-radon mixture that contains ~1.05 million pCi/L Radon-222. Since leachate and landfill gas are reasonable analogs of water and air, landfill leachate that contains ~270,000 pCi/L dissolved Radon-222 is approximately at equilibrium with an overlying landfill gas mixture that contains ~1.05 million pCi/L Radon-222.

37. DEC is incorrect in claiming (Responsiveness Summary at 7) that results are "misleading" and that "no support (i.e., source citation that has been subject to scientific peer review and publication, or even the calculation itself)" has been provided for the concentration of ~1.05 million pCi/L of radon within the landfill waste mass. On the contrary, I have provided ample citations to support my analysis.[32]

Landfill Modeling Studies

38. The evidence of high levels of radon in the Hakes landfill leachate is supported by

[31] For example, a 1908 paper by Kofler on partitioning of radon between water and gas phases is cited by A.B. Tanner, "Radon Migration in the Ground: A Supplementary Review," in T.F. Gesell and W.M. Lowder, eds., *Natural Radiation Environment III*, proceedings of a 1978 DOE/University of Texas symposium in Houston (1980), Vol. 1, at 14.

[32] For example, see my 2019 Memorandum at 12-21, my 2018 Affidavit at 25-27, and authoritative sources cited therein.

modeling studies by Walter et al. (2012) which show downwind radon impacts from a roughly similar landfill.[33] These authors found 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." Their work provides independent evidence that high levels of radon, generated within a landfill by radium-bearing waste, cannot be dismissed as far-fetched or impossible.

39. DEC has relied partly on two landfill modeling studies by Argonne National Laboratory (Smith et al. 1999, and Harto et al. 2014) to show that impacts from radioactivity are minimal, even from a modeled landfill that accepts radium-bearing waste up to 50 pCi/g radium, which is twice the nominal limit for Hakes landfill. Neither of these studies, however, provides a quantitative assessment of radon levels (in either leachate or landfill gas) within the landfill. Moreover, neither study addresses or provides a quantitative assessment of radon emissions through the cap of the modeled landfill. Thus, neither study provides enough scientific detail to refute the evidence presented here of high radon levels in Hakes landfill.[34] The 2012 modeling study by Walter et al.[35] is not cited or acknowledged by DEC but provides more quantitative – and thus more useful – information than is found in the two Argonne modeling studies on which

---

[33] See 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), and my 2019 Memorandum at 25-26 for justification of the above statement that the Hakes landfill can be considered "roughly similar" to the landfill modeled by Walter et al. The latter landfill assumes a higher radium level in its waste (50 pCi/g versus 25 pCi/g limit), but its radon concentration in landfill gas is less (on the order of 300 to 20,000 pCi/L rather than 1 million pCi/L).

[34] See my 2019 Memorandum at 24-26. Smith et al. evaluate radon doses and risks to the offsite public from air emissions released *during waste placement* but do not report assumptions and findings on the presence, concentration, and effects of radon in landfill gas. See K.P. Smith et al., *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), at 34 and 48. See also C.B. Harto et al., *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), at 21, 61, and 63.

[35] Walter et al., op. cit.

DEC has relied. Like those two Argonne studies, the study by Walter et al. uses a modeled landfill that accepts radium-bearing waste up to 50 pCi/g radium, which is twice the nominal limit for Hakes landfill.

40. The Walter et al. study is relevant because it provides quantitative information indicating 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. See my 2019 Memorandum at 25 for details.[36] This provides a basis for comparison because the level of radium in landfill waste will be roughly proportional to the level of radon in landfill gas, other factors being equal.

41. Such a comparison shows that, if the landfill modeled by Walter et. al contains 50 pCi/g radium in its waste and produces 300 to 20,000 pCi/L of radon in its landfill gas, then a landfill such as Hakes would need to contain about 2500 to 175,000 pCi/g radium in its waste to produce ~1 million pCi/L of radon in its landfill gas. Whether Hakes landfill actually contains radium-bearing waste that approaches 2500 to 175,000 pCi/g radium – a range far beyond the landfill's nominal acceptance limit of 25 pCi/g – is unlikely but remains an unanswered question. It's a question that needs to be answered definitively by testing, not by rough comparison to a modeled landfill. Nevertheless, the rough comparison in this paragraph serves as one more warning or caveat that the claimed low level of radium in the Hakes landfill waste (less than 25 pCi/g) can't be reconciled with the intermittently high radon levels indicated by the Hakes leachate test results.

[36] In my 2019 Memorandum at 25, note the typographical error in the next-to-last line on that page, where "…300 to 20,000 pCi/g..." should be "…300 to 20,000 pCi/L..." In other words, "pCi/g" should be "pCi/L" in that phrase, as is evident from the preceding sentence. Also at 27, where 200,000 "pCi/g" should be 200,000 "pCi/L."

Possible Effects of Local Geology

42. Although Respondents point to the local geology as a possible source for the radioactivity in the landfill, they offer no explanation or support for how radon levels as high as ~270,000 pCi/L in the landfill leachate and as high as ~1 million pCi/L in the landfill gas could possibly be derived from the local geology.

43. It is well-known and apparently undisputed that local soils and near-surface rock contain no more than about 1 pCi/g of Radium-226.[37] It is unclear whether Respondents are relying on this aspect of local geology, or on upwelling radon from deeper geologic sources, but neither is capable of explaining radon levels as high as ~270,000 pCi/L in Hakes landfill leachate or as high as ~1 million pCi/L in the landfill gas.

44. Deeper geologic media may convey radon upward into the pores of the unconsolidated near-surface materials, and potentially into the landfill, but in the immediate vicinity of the landfill the liner acts as a top seal on the deeper geology, effectively isolating the leachate and landfill gas from upwelling deep-source radon. See my 2019 Memorandum at 28. There is no plausible explanation, and Respondents have not offered any, for how deep-source radon could penetrate the liner in sufficient quantity to account for radon levels as high as ~270,000 pCi/L in the leachate or as high as ~1 million pCi/L in the landfill gas.

45. Locally-sourced landfill cover materials, particularly the 18-inch layer of unclassified soil and 6-inch layer of topsoil,[38] contain radium at a level of no more than about 1 pCi/g but cannot account for radon levels as high as ~270,000 pCi/L in the leachate or as high as ~1 million pCi/L in the landfill gas. This can be roughly demonstrated, as a limiting case, for

[37] For example, in the Hakes FSEIS, Appendix 5, see the 5/16/2018 CoPhysics report at 13 for the range of 0.5 to 1 pCi/g radium in general soil or rock, and the range of 0.1 to 0.2 pCi/g radium in topsoil.

[38] Hakes DSEIS, Appendix C, esp. Fig. C-4.

Hakes landfill cell 8B which is 4.7 acres in area[39] and has a leachate storage volume of roughly 2 million liters.[40] This storage volume may not have been entirely filled with leachate at the time of the 6/6/17 sampling which showed ~6000 pCi/L Lead-214 and Bismuth-214 at the time of sample testing (hence ~270,000 pCi/L radon at the time of sample collection), but the volume of cell 8B leachate at that time would have ranged from a few hundred thousand liters[41] up to a maximum of ~2 million liters. This volume of leachate, having been representatively sampled, must have contained a total of about 80 to 500 millicuries of Radon-222.

46. The 18-inch and 6-inch layers of landfill cover soil noted above, totaling 24 inches in thickness over the 4.7-acre area of cell 8B, must have weighed approximately 25,000 tons or about 2.3×10^{10} grams, and must have contained a total of about 23 millicuries of Radium-226 at a level of ~1 pCi/g. Even if this entire quantity of capping soil and its 23 millicuries of radium were temporarily enclosed (sealed) for at least 21 days to achieve secular equilibrium, thereby producing 23 millicuries of radon and preventing any of this radon from escaping upward into the atmosphere as it would ordinarily do, and even if the entire 23 millicuries of radon were then washed down into the aforementioned volume of landfill leachate, these 23 millicuries of radon would not be enough to provide the 80 to 500 millicuries of radon (see above) that must be accounted for in the leachate. This is a limiting case, in the sense that far less than 23 millicuries of radon would be able to reach the leachate because of upward escape of radon, and because barrier properties of the cap/cover system would limit the ability of rainfall to percolate downward and carry all remaining radon into the leachate. This is a rough

[39] Hakes Part II Engineering Report, prepared for Casella Waste Systems by McMahon & Mann, May 2019, Appendix C-1.

[40] Estimated in proportion to 3-acre cell 9A which has a storage volume of 339,379 gallons. Id.

[41] Based partly on the landfill's monthly average leachate generation rate of 8233 gallons/acre/month. Id.

comparison that shows that the local geology explanation doesn't work. And without local geology as an explanation, the claimed low level of radium in the Hakes landfill waste (less than 25 pCi/g) remains unreconciled with the intermittently high radon levels indicated by the Hakes leachate test results.

Effectiveness of the Entrance Monitors

47. In support of its assertion that high levels of radium and radon in the landfill are either not possible or are naturally occurring, DEC relies heavily on the claim that the landfill's entrance monitors have not detected radioactivity in waste entering the landfill. DEC's reliance on the entrance monitors assumes that the entrance monitors are effective at detecting radioactivity in the wastes that pass through. This is not so. As I have explained, the entrance monitors cannot reliably discriminate between truckloads of waste that meet DEC's 25 pCi/g radium limit and truckloads containing much greater levels of radium.[42] The monitors rely principally on the measurement of gamma radiation from the radium decay products Lead-214 and Bismuth-214 rather than direct measurement of radium, thereby assuming a constant degree of *equilibrium* between radium and its decay products. Yet there can be substantial *disequilibrium* in waste truckloads due to radon being allowed to off-gas from the load. If the load has not been tightly sealed, radon will off-gas from the load and this will result in artificially low levels of the radon decay products Lead-214 and Bismuth-214 being present, causing the gamma monitors to misinterpret the radium concentration in the load. In this way, truckloads of waste substantially exceeding 25 pCi/g radium are able to enter the landfill without tripping the monitors. Waste truckloads with up to 60-fold variations in their Radium-226 concentrations

[42] See e.g. my 2018 Affidavit at 8-16.

(activities) may exhibit the same or similar monitor readings.[43]

48. As an illustration of the disequilibrium between radium and its decay products that can occur in radium-bearing landfill materials, see work done by Krysiak at a coal ash landfill at Wright-Patterson Air Force Base.[44] He found that the "difference between the activities of the nuclides above and below ^{222}Rn indicates that a large fraction of ^{222}Rn escapes the soil," meaning that he found substantial disequilibrium between Radium-226 and its decay products Lead-214 and Bismuth-214, with the latter two being in equilibrium with each other.[45] Materials such as these, even without any manipulative attempt to remove additional radon, would pass through a gate monitor with an artificially low monitor reading that was well below its actual radium concentration.

49. For entrance monitors to be effective, the monitors must be able to perform direct measurement of radium. The monitors installed at the Hakes landfill cannot do this.

Significance of Recent Lead-210 Test Results

50. Recent Lead-210 testing of February 2018, November 2018 and May 2019 leachate samples does not rule out intermittently high radon levels in leachate and landfill gas.[46] These results indicate that Radon-222 at the time of sample collection ranged as high as a few thousand pCi/L in the samples. The February 2018 tests were performed on leachate samples in which Lead-214, Bismuth-214, and radon were *not* high, and the November 2018 and May 2019 tests were done after Method 901.1 testing for Lead-214 and Bismuth-214 was discontinued.

---

[43] Id., esp. ¶¶ 28-29.

[44] R.S. Krysiak, Jr., "Determining the Effects of Waste Coal Ash on Landfill Radon Levels," M.S. Thesis, U.S. Air Force Institute of Technology (1995), https://apps.dtic.mil/dtic/tr/fulltext/u2/a306367.pdf.

[45] Id. at 73; also his Tables 4.0 and 4.6.

[46] Lead-210 testing was performed on leachate samples collected February 27, 2018, November 8, 2018 (4Q2018), and May 1, 2019 (2Q2019), as shown in the Hakes radiological test report for 2Q2019. The 4Q2018 test results for Lead-210 are shown in Table 1 of the 2Q2019 test report but are inexplicably absent from the 4Q2018 report.

Such results do not rebut earlier test results from leachate samples that were not tested for Lead-210 but showed high levels of Lead-214 and Bismuth-214.

Conclusion

51. Petitioners rely on unrefuted evidence from the landfill's own leachate tests that shows concentrations of radium decay products that are far too high to be explained by any of the theories offered by Respondents. The leachate evidence points to radium levels in the landfill that substantially exceed DEC's 25 pCi/g regulatory standard. In their responses to Petitioners' leachate evidence, DEC and the landfill operator rely on unsupported assumptions, based on which they dispute – but fail to rebut or explain – the above evidence for high levels of radium and its decay product radon.

52. In my opinion, there is no substantial evidence to support the findings regarding radioactivity and health risks that are expressed in the positive findings statements issued by DEC and the Town of Campbell.

53. In addition to evidence relating to current high levels of radium and its decay product radon, it's important to recognize that expansion will accommodate more waste and that landfill-gas emissions from an expanded Hakes landfill may triple from their present rate (see DSEIS, Appendix H, at 7), potentially increasing downwind health risks relative to current levels. This type of impact from landfill expansion needs to be characterized, starting with a credible characterization of the presence, levels, and locations of radium and radon within the current landfill and its proposed expansion.

54. Measurement of the radon gas emanating from the landfill gas collection system can and should be conducted, as I described in a memorandum dated March 5, 2019 that Petitioners presented to the Town of Campbell and DEC on the following day. Direct tests of

radon levels in the landfill gas would remove all doubts Respondents have raised regarding the validity of my calculations and would provide a further check on the reliability of the landfill's entrance monitors.

This affidavit is based on information available to me at this time. Should additional information become available, I reserve the right to determine the impact, if any, of the new information on my opinions and conclusions and to modify or supplement this affidavit if necessary.

Sworn to before me this 13th day of February 2020.

Notary Public

AMBER A WIKTOROWSKI
NOTARY PUBLIC STATE OF NEW YORK
ERIE
LIC. #01WI6377459
COMM. EXP. 07/02/2022

TABLE OF EXHIBITS