# A Critique of the Radioactive Waste Management Associates' "Radioactivity in Marcellus Shale" Report

Ralph H. Johnson[1]
Blank Rome LLP, Washington, D.C.
September 15, 2010

## Introduction

Dr. Marvin Resnikoff and other associates of Radioactive Waste Management Associates prepared a document entitled, "Radioactivity in Marcellus Shale," dated May 19, 2010.[2] The document concerns the supposed radiological impact of permitting Marcellus shale cuttings to be placed in landfills. A review of the document reveals significant inadequacies, misstatements, and errors that are discussed in this memorandum. Specifically, this document will show that Resnikoff does not have sufficient training or experience in health physics to properly analyze the radiological impact of placing Marcellus shale cuttings in a landfill. It is particularly noteworthy that Resnikoff's radiation dose calculations and health physics opinions have been rejected by both a federal and a state court. His dose calculations in this instance are based upon his mischaracterization of Marcellus shale cuttings and misuse of available data. He relies upon relatively weak information (*e.g.,* a gamma ray log) and essentially ignores more reliable evidence (*e.g.,* the actual measurements of radioactivity in the shale cuttings collected by the New York State Department of Environmental Conservation). The hypothetical resident farmer's dose that Resnikoff calculates is based upon scientifically absurd assumptions. Resnikoff misrepresents the health effects of radium inhalation and ingestion. He concedes that his radium detection calculations are wrong by a factor of 1,000. In sum, Resnikoff opinions are not reliable and they should be rejected.

## 1. Resnikoff's insufficient health physics background

Summary: *Resnikoff does not have sufficient health physics training and experience to reliably determine the radiological impact of shale cuttings on a landfill environment. A state and a federal court have determined that his opinions are not based on reliable methodology*.

[1] Ralph H. Johnson is an attorney who has practiced radiation law for over 30 years. He led the U.S. Department of Justice Radiation Litigation Team and has represented numerous companies in radiation-related lawsuits. The health physics calculations and scientific concepts in this memorandum were reviewed for accuracy by two certified health physicists. Mr. Johnson has been defense counsel in several cases where Dr. Resnikoff has appeared as a plaintiffs' expert witness.

[2] The authors of the Radioactive Waste Management Associates' document are collectively referred to as "Resnikoff" throughout this memorandum. This memorandum also discusses pertinent statements in Resnikoff's June 30, 2010 memorandum to G. Abraham regarding the June 9, 2010 New England Waste Services of New York document filing.

The subject of health physics includes the measurement of radiation and the study of the health effects caused by radiation exposure. Many of the statements made in Resnikoff's report[3] pertain to the subject of health physics. Resnikoff has no formal training in radiation dosimetry or dose reconstruction, other than one undergraduate course taken during the 1950s.[4] Resnikoff failed the examination to be certified as a health physicist and has not retaken the examination.[5]

Resnikoff states that he has written books on radioactive waste issues. Resnikoff's book, *Living Without Landfills*, was reviewed by a committee of the National Council on Radiation Protection and Measurements. The NCRP committee found that Resnikoff's book was "misleading," because it: (1) "excluded relevant information," (2) "contained misstatements of fact," (3) "contained many exaggerations," (4) "exhibited bias," and (5) "contained many instances of faulty logic."[6]

Resnikoff states that he has been involved in litigation involving land contamination in Louisiana. In the *Harvey Term* litigation, the Louisiana state district court rejected Resnikoff's dose calculations and opinion, finding that they were "fatally flawed" because he relied upon an "outlandish premise."[7] Resnikoff's "outlandish premise" was that all of the residents in the vicinity of a petroleum pipe-cleaning facility remained constantly in their yards for 30 years; *i.e.*, they stood outdoors 24 hours per day, 365 days per year for 30 years.

Resnikoff also attempted to testify as an expert on health physics in a Florida federal court. The court rejected Resnikoff's proposed testimony, finding that his "false assumptions" made his methodology unreliable.[8]

Resnikoff overstates his credentials, claiming in his report that "[i]n June 2000, he was appointed to a Blue Ribbon Panel on Alternatives to Incineration *by DOE Secretary Bill Richardson*."[9] In fact, the "nine-member panel was composed of five members appointed by the Secretary of Energy, one member appointed by each of the governors of Idaho and Wyoming, and two members appointed by public interest groups."[10] Resnikoff

---

[3] "Radioactivity in Marcellus Shale," Resnikoff *et al*. (May 19, 2010) ("Resnikoff report").
[4] Resnikoff deposition, *Ray v. Ashland*, Civil Action No. 97-CI222, Lawrence Circuit Court, Kentucky (December 11, 2007), p. 17.
[5] *Id.*, pp. 22-23.
[6] "Review of the Publication, *Living Without Landfills*" (NCRP Commentary No. 5), National Council on Radiation Protection and Measurements (July 31, 1989), p. 1
[7] *In re Harvey Term Litigation,* Civil Action No. 02001-8708, Parish of Orleans Court, Louisiana (April 14, 2008), pp. 12-14.
[8] *Finestone v. Florida Power & Light Co.,* 2006 U.S. Dist. LEXIS 7743 (January 6, 2006), p. 11.
[9] Resnikoff report, p. 1.
[10] "Report of the Secretary of Energy Advisory Board's Panel on Emerging Technological Alternatives to Incineration," Secretary of Energy Advisory Board, U.S. Department of Energy (December 2000), p. 2.

likely was not appointed by Secretary Richardson. According to an April 2000 press release, he was not on the list of panel members appointed by the Secretary.[11] Instead, a June 27, 2000 Associated Press article indicates that the Snake River Alliance nominated Resnikoff "to the final seat on the … panel."[12] The difference between selection by a cabinet secretary (as claimed by Resnikoff) and a public interest group (as reported in the press) is substantial and could affect Resnikoff's credibility.

2. Resnikoff's incorrect claims about the radionuclide content of shale

Summary: *Resnikoff's opinion about the impact of disposing Marcellus shale cuttings is based upon his estimates of the concentration of uranium and its decay products (e.g., radium-226) in the cuttings. His cuttings concentration estimates rely upon data in three documents:*

*a. analyses of the uranium concentration in Marcellus shale performed by the U.S. Geological Survey (Resnikoff misinterprets the analyses as showing "extremely high" concentrations of uranium);*

*b. actual measurements by the New York State Department of Environmental Conservation of the radium-226 concentration in Marcellus shale cuttings (Resnikoff erroneously claims they are "far higher than background," but the Department of Environmental Conservation found that the radium levels were "essentially background"); and*

*c. a so-called "typical" gamma-ray log that Resnikoff admits he cannot read accurately because of its quality (Resnikoff substantially miscalculates the radium-226 concentration indicated by the gamma-ray log).*

Resnikoff's objection to the disposition of Marcellus shale cuttings in landfills is based on his claims regarding the content of uranium and its daughter products in the shale cuttings. These claims are premised in part upon four samples analyzed by the U.S. Geological Survey. Resnikoff asserts that "the uranium content in the four samples is *extremely high* … and measures up to 83.7 parts per million …."[13] The International Atomic Energy Agency, however, classifies uranium ore with a content of 83.7 ppm as

[11] "Blue Ribbon Panel to Examine Alternatives to Incineration," GovCon website (May 16, 2000); accessed at http://www.govcon.com/article.mvc/Blue-Ribbon-Panel-to-Examine-Alternatives-to-0001?VNETCOOKIE=NO on August 30, 2010; *see also* "Blue Ribbon Panel Checks Alternatives to Burning Radioactive Waste," AmeriScan website (April 25, 2000); accessed at http://www.state.nv.us/nucwaste/news2000/nn10607.htm on August 30, 2010; and "Blue Ribbon Panel on Technology Alternatives to Incineration Established," DOE News (April 25, 2000); accessed at http://newsdesk.inl.gov/press_releases/2000/Blue_Ribbon_Pan.htm on August 30, 2010.

[12] "Idaho group nominates expert for incineration alternative panel," Associated Press; accessed at http://www.state.nv.us/nucwaste/news2000/nn10696.htm on August 30, 2010.

[13] Resnikoff report, p. 5.

"very low grade."[14] Alternatively, the IAEA considers an uranium content of 5% to 15% (or 50,000 ppm to 150,000 ppm) to constitute a "high to very high grade" ore.[15] The uranium content is this higher grade of ore is hundreds to thousands of times higher than the very low uranium content in the shale that Resnikoff erroneously considered to be "extremely high."

Some of the information that Resnikoff provides regarding the four USGS cores listed on page 4 of his report is not reliable. The coring, for example, that Resnikoff claims was collected in Allegheny (*sic*) County, New York, was actually collected in Allegheny County, Pennsylvania.[17] Further, the Knox County, Ohio, samples that Resnikoff claims are from the Marcellus formation are actually from other, more shallow formations, according to the USGS.[18]

Focusing only upon the higher USGS core uranium concentrations, Resnikoff contends "that the radioactivity of the Marcellus formation remains consistently high throughout." In fact, however, the uranium concentration in the several USGS Marcellus cores selected by Resnikoff[19] varies by almost an order of magnitude: from essentially background (8.9 ppm) to a maximum of 83.7 ppm. The mean uranium concentration in the cores (which Resnikoff does not include in his report) is only 34.4 ppm, which equates to approximately 11.27 pCi/g of radium-226; and the median uranium

[14] "World Distribution of Uranium Deposits with Uranium Deposit Classification" (IAEA-TECDOC-1629, 2009 Edition), International Atomic Energy Agency, p. 58. Low grade ores, according to the IAEA, include those with uranium contents of 25 to 150 ppm
[15] *Id.*, p. 16.
[17] "Geochemistry of trace elements and uranium in Devonian shales of the Appalachian Basin" (Open File Report 81-778, 1981) Leventhal *et al.,* U.S. Geological Survey. The USGS uranium content for the Allegany County, New York, samples is 3.2 to 8.1 ppm (p. 23). The maximum USGS uranium content for the Allegheny County, Pennsylvania, samples is 67.7 ppm (p. 10) – the maximum value that Resnikoff incorrectly attributes to Allegany County, New York.
[18] *Id.,* pp. 5, 32 and 36.
[19] The mean and median values are based upon the USGS Marcellus shale data for the Allegheny County, Pennsylvania (misidentified by Resnikoff as Allegany County, New York) – 8.9 ppm (questionable Marcellus shale), 11 ppm (questionable Marcellus shale), 67.6 ppm (*id.,* pp. 3, 10, 28, 32); Tompkins County, New York – 29, 25, 53, 11 ppm (*id.,* pp. 5, 21); Livingston County, New York – 19.9, 16.6, 83.7, 53.8 (*id.,* pp. 5, 22); the Knox County, Ohio, samples are not included in the calculations because the USGS did not identify Marcellus shale in the samples from that county (*id.,* pp. 5, 32, 36, 37).

concentration is only about 25 ppm, which equates to about 8.19 pCi/g of radium-226.[20]

Resnikoff refers at page 5 (footnote 7) of his report to the radium-226 concentrations in Marcellus shale in the New York State Department of Environmental Conservation report.[21] Resnikoff falsely states that the radium levels in the two New York DEC's two Marcellus shale samples are "far higher" than the New York State background concentration.[22] In fact, the radium-226 concentration (0.87 pCi/g) in the first state sample – the Blair 2A (Steuben County) sample – is almost identical to the New York natural radium concentration (0.85 pCi/g) that Resnikoff identifies in his report.[23] The radium-226 concentration in the other state sample – Crouch C 4H from Madison County at 1.84 pCi/g – is slightly above the published background range referenced by Resnikoff (0.48-1.2 pCi/g),[24] but well within the 5 pCi/g total radium average background value that the state DEC has measured for radium-226 and radium-228 combined.[25]

Contrary to Resnikoff's exaggerated claim that the levels in the DEC Marcellus samples are "far higher" than background, the DEC described the concentrations in the

---

[20] The median uranium value of 25 ppm indicates a uranium-238 content of 24.82 ppm (or micrograms/gram) x uranium-238 specific activity of 0.33 pCi/microgram = 8.19 pCi/g. *See* "Exposures from the Uranium Series with Emphasis on Radon and Its Daughters" (NCRP Report No. 77), National Council on Radiation Protection and Measurements (1984), p. 101. Assuming, as Resnikoff does at p. 5 of his report, that uranium-238 and radium-226 are in secular equilibrium, the radium-226 concentration is approximately 8.2 pCi/g.

[21] "Draft Supplemental Generic Environmental Impact Statement on the Oil, Gas and Solution Mining Regulatory Program" (September 2009) ("DEC draft report"), New York State Department of Environmental Conservation, Division of Mineral Resources, Table 5-2 ("2009 Marcellus Radiological Screening Data"), p. 5-30.

[22] Resnikoff obviously confuses the *total* radioactivity levels for the two state samples (25.4 and 29.2 pCi/g) with the radium concentrations for the samples (1.843 and 0.872 pCi/g). Resnikoff report, p. 5, footnote 7.

[23] *Id*.

[24] "Determination of Concentrations of Selected Radionuclides in Surface Soils in the U.S.," Myrick *et al., Health Physics*, Vol. 45, No. 3 (1983), Table 1, p. 635.

[25] "An Investigation of Naturally Occurring Radioactive Materials (NORM) in Oil and Gas Wells in New York State, Executive Summary," New York State Department of Environmental Conservation, p. 5; accessed at http://www.dec.ny.gov/chemical/23473.html on August 30, 2010. The combined concentration of radium-226 and radium-228 (actinium-228) in the Madison County sample is 2.693 pCi/g; *i.e.,* less than 5 pCi/g. Note that actinium-228 is a radiological surrogate for radium-228 (Resnikoff agrees at page 9 of his report).

samples as "levels of radioactivity that are essentially background values."[26] Resnikoff mistakenly concludes that the low radium content in the DEC samples is consistent with the radium content indicated by a gamma-ray log that he misinterprets as demonstrating "high radioactivity."[27] Ironically, the gamma-ray log misinterpreted by Resnikoff, shows near-background radium concentrations of 1.44 to 2.89 pCi/g,[28] which are, in fact, consistent with the "essentially background" radium concentrations in the DEC samples.

Resnikoff assumes that a portion of a gamma ray log of a well in Shiavone, New York, represents Marcellus shale.[29] And, he admits in his April 7, 2010 report that "it is not possible to give the specific radioactivity measurement due to the log quality," but he assumes a "gamma ray range of 200-400 GAPI" (*i.e.,* API units) for Marcellus shale.[30] He equates the supposed 200-400 API unit range with "radium concentrations of about 12-24 pCi/g or higher"[31] – an error explained below.

Resnikoff's radium-226 concentration derived from the gamma ray log is about one order of magnitude too high.[32] In fact, a gamma ray log reading of 200-400 API units actually indicates a radium-226 concentration of approximately 1.43 to 2.86 pCi/g,

---

[26] DEC draft report, p. 5-30. It is noteworthy that predominant source of radioactivity in the state samples is potassium-40 at concentrations of 14.438 and 22.845 pCi/g. The range of potassium-40 in typical rock is 1.89 to 40.5 pCi/g. *Environmental Radioactivity*, Eisenbud and Gesell (4th ed., 1997), Table 6-6, p. 140.

[27] Resnikoff report, p. 5.

[28] *See* footnote 33 below.

[29] Memorandum from M. Resnikoff to Gary Abraham, dated April 7, 2010 regarding "Radioactivity in Marcellus Shale," p. 2.

[30] *Id*.

[31] *Id.*

[32] Resnikoff claims that "16.5 GAPI units = 1 pCi/g." *See* Resnikoff report, p. 5, footnote 6. Resnikoff's April 7, 2010 report states at p. 2: "In order to convert the GAPI units to curies we used a method cited by several sources, in which 16.5 GAPI units equal 1 microgram of radium-equivalent per metric ton (or 1 picocurie per gram)." The "radium equivalent," however, is based not only upon the radium (or uranium) concentration per metric ton, but the thorium and potassium-40 concentrations as well, which Resnikoff apparently did not consider. *See* "Answer to Question #5434 Submitted to 'Ask the Experts,'" Answered by Paul Frame, CHP, PhD; Health Physics Society website accessed at http://www.hps.org/publicinformation/ate/q5434.html on August 30, 2010.

not 12-24 pCi/g as claimed by Resnikoff.[33] Similarly, the radium-228 associated with a gamma ray log reading of 200-400 API units would also be low – 2.22 to 4.45 pCi/g.[34] The combined radium-226 and radium-228 concentrations (3.66-7.33 pCi/g) are similar to the average total radium background ("around 5 pCi/g") in New York reported by the Department of Environmental Conservation.[35] The values are also similar to the radium soil concentration of 5 pCi/g that the U.S. Environmental Protection Agency has stated "would provide for a reasonably reduced risk from long term exposure."[36]

3. Resnikoff's claims regarding radium in flowback fluid

Summary: *The Department of Environmental Conservation and the landfill operator have agreed that "flowback water related filter sludge, production brine related*

[33] API units are based on the North American Shale Composite Reference Standard where a gamma ray log reading of 121.7 API units is associated with a thorium concentration of 12.3 ppm, a uranium concentration of 2.66 ppm, and a potassium percentage of 3.2%. *See* Kansas Geological Survey website at http://www.kgs.ku.edu/PRS/ReadRocks/GRLog.html, accessed on August 30, 2010; *see also* "Borehole Geophysics" lecture by Professor Michael Riedel of McGill University at http://eps.mcgill.ca/~courses/c550/borehole-lecture05-nuclear-methods.pdf; accessed on August 30, 2010. A uranium concentration of 2.66 ppm (or a 99.27% uranium-238 concentration of 2.64 ppm) is equal to 0.9 (0.88) pCi/g of uranium-238. This is based on the equation: specific activity of uranium-238 (0.33 pCi/microgram) x uranium concentration (2.66 ppm or micrograms/gram) = 0.9 (0.88) pCi/g. Where uranium-238 and radium-226 are in secular equilibrium, as Resnikoff assumes at p. 4 of his report, the radium-226 concentration is equal to the uranium-238 concentration of 0.9 pCi/g. Thus, where the radium-226 concentration associated with a gamma log reading of 121.7 API units is 2.66 ppm or 0.9 pCi/g, then the radium-226 concentration associated with a gamma log reading of 200-400 API units would be 1.43 to 2.86 pCi/g.

[34] According to the North American Shale Composite Reference Standard, a gamma ray log reading of 121.7 API units is associated with a thorium concentration of 12.3 ppm. Thorium-232 comprises over 99% of the total thorium and it has a specific activity of 0.00000011 Ci/g ("Thorium," Argonne National Laboratory (2005), available at: http://www.evs.anl.gov/pub/doc/Thorium.pdf). Thus, the 12.3 ppm (micrograms/gram) associated with the Reference Standard 121.7 API units would indicate a thorium-232 concentration of 1.353 pCi/g (12.3 ppm [micrograms per gram] x 0.11 pCi/microgram = 1.353 pCi/g); and 200-400 API units would indicate a thorium-232 concentration of 2.22 - 4.45 pCi/g. Assuming the equilibrium of thorium-232 and radium-228, the radium concentration similarly would be 2.22 – 4.45 pCi/g.

[35] "An Investigation of Naturally Occurring Radioactive Materials (NORM) in Oil and Gas Wells in New York State, Executive Summary," New York State Department of Environmental Conservation, accessed at http://www.dec.ny.gov/chemical/23473.html on August 30, 2010.

[36] "Radiation Protection at EPA" (EPA 402-B-00-001, August 2000), U.S. Environmental Protection Agency, p. 36.

*filter sludge, and free-phase liquids of any origin, are prohibited from disposal."*[37] *Thus, Resnikoff's overstatement of the risk of radium in the flowback and other liquid wastes is not relevant. The following discussion shows the extent of Resnikoff's exaggerations.*

The New York State Department of Environmental Conservation draft supplemental generic environmental impact statement at page 5-100 states that "[f]lowback fluids include the fracturing fluids pumped into the well, which consists of water and additives …; any new compounds that may have formed due to reactions between additives; and substances mobilized from within the shale formation due to the fracturing operation." Further, the draft statement states at page 5-97 that "[b]oth the process and the returned water are commonly referred to as "flowback."

Resnikoff exaggerates the radium concentration in the flowback fluid at pages 6 and 7 of his report. He does this by ignoring the actual measured flowback radium concentrations (ranging from 2.58 to 33 pCi/l for radium-226, and 1.15 to 18.41 pCi/g for radium-228) reported in the DEC environmental impact statement.[38] Instead of relying upon actual measured values contained in the DEC report, Resnikoff baselessly assumes that the flowback fluid will have the same radium concentration as the Marcellus brine, which he claims to be 15,000 pCi/l.[39] By assuming the flowback fluid has the same radium concentration as brine, he bases his flowback-related calculations on radium concentrations that are hundreds to thousands of times higher than the actual measured concentrations reported by the state.

Resnikoff states at page 6 of his report that "not all of the liquid waste in which the drill cuttings are suspended will be removed." This statement is contradicted by his colleague, Dr. Anthony Ingraffea, who visited a Pennsylvania drilling pad and was informed that the wet cuttings are "dewater[ed]" and "are further processed by putting them through a device that aerates by blowing air through the materials as they are tumbled, resulting in a dry powder-like residue. This powder-like residue is the cuttings ready for disposal in a landfill."[40] Contrary to Ingraffea's report, Resnikoff assumes at page 7 of his report that up to 20% of the cuttings waste is liquid.

Even if each cubic meter of cuttings contains 20% flowback fluid at the 15,000 pCi/liter concentration assumed by Resnikoff, the radium in a cubic meter of waste containing 20% produced water would be less than the radium in a cubic meter of waste

---

[37] June 30, 2010 letter from Lisa Perla Schwartz, Assistant Regional Attorney, to Edward Buhrmaster, Office of Hearings and Mediation Services, New York State Department of Environmental Conservation, pp. 5-6.

[38] DEC draft report, Table 5-10 ("Concentrations of NORM constituents based on limited samples from Pennsylvania and West Virginia"), p. 5-110.

[39] Resnikoff report at p. 6. Actually, the Marcellus production brine ranged from 0.163 pCi/l to 16,030 pCi/l, with a mean of 5,459 pCi/l and median of 4,049 pCi/l. DEC draft report, Appendix 13 ("NYS Marcellus Radiological Data from Production Brine").

[40] May 17, 2010 letter from Anthony Ingraffea to Gary Abraham regarding "Cuttings Waste Disposal at Chemung County Landfill," p. 5.

with no water.[41] So, Resnikoff's concern at page 6 that a "considerable amount of contaminated drilling fluid will be disposed in the … landfill with drill cuttings" actually means that the radium activity per cubic meter will be less than if the cuttings were dried as Ingraffea reported.

Resnikoff states at page 7 that the radium in the cuttings will become part of the leachate at the landfill. Studies, however, have shown that radium leaches extremely slowly – "that the annual mobilization rate is on the order of $10^{-7}$. One of the principal reasons for the slow rate of mobilization is the tenacity with which radium is sorbed on *clays* and organic materials."[42] As noted by Resnikoff on page 7 of his report, "landfills are lined with a layer of *clay*…."

4. Resnikoff's incorrect dose calculations

Summary: *Resnikoff used the Argonne National Laboratory RESRAD dose calculation program to estimate landfill worker and resident farmer doses; he found the doses excessive. If, however, reasonable assumptions, are employed in operating the RESRAD program, the resulting landfill worker doses are below the occupational and public dose limits, and the hypothetical resident farmer's dose is essentially zero.*

Resnikoff states at pages 6 and 7 that if "landfill workers … come in contact with" the shale cuttings their doses "would exceed current health-based dose limits."[43] The occupational dose limit is 5,000 millirem/year; the public dose limit is 100 millirem/year.[44] Even if a worker stood 8 hours per day directly on top of the cuttings in

[41] Resnikoff assumes that the radium-226 concentration of the cuttings is 20 pCi/g at p. 7 of his report. Where the oil shale cuttings have a density of approximately 2.5 g/ml, the mass of 1 cubic meter of cuttings would be 2.5E+06 g. At a cuttings radium concentration of 20 pCi/g, the radium-226 in the cubic meter of dry cuttings would be 5E+07 pCi. A cubic meter of waste containing 80% cuttings powder (4E+07 pCi) and 20% produced water (15,000 pCi/liter x 200 liters [*i.e.,* 20% of 1 cubic meter] = 3E+06 pCi) would contain 4.3E+07 pCi – or less radium-226 than the cubic meter of dry cuttings (5E+7 pCi).

[42] *Environmental Radioactivity*, Eisenbud and Gesell (4th ed., 1997), p. 111; *see also* "Human Health Fact Sheet – Radium," Argonne National Laboratory, p. 2: "… it is even less mobile in clay soils, with concentration ratios over 9,000." "Radionuclides in Produced Water – A Literature Review," E. Snavely (American Petroleum Institute, 1989), p. 49: "In the environment, radium behaves much like the other alkaline earth elements barium, strontium, and calcium. These elements form insoluble sulfates, they are strongly absorbed by clays…. Fine clays … have very high absorption capacities for radium."

[43] Resnikoff refers at p. 7 to the remediation standards for inactive uranium processing sites, 40 C.F.R. §192.12, which are not applicable to landfills which that accept oil/gas shale cuttings.

[44] New York State Department of Labor Code Rule 38, Sections 38.18(a)(1)(i)(a) and 38.19(a)(1)(ii).

a landfill, his dose from the pertinent occupational pathways (external radiation, dust inhalation, radon, and soil ingestion) would not exceed the occupational or the public dose limits.[45]

Resnikoff's dose calculation for a future farmer building a home directly on top of the shale cuttings is based upon a number of absurd assumptions, including the existence of a garden, orchards, and a wheat field grown directly on top of the oil shale cuttings (*i.e.,* non-organic, powdered rock*)*, from which 350 pounds of food are improbably harvested each year.[46] Most jurisdictions, of course, would not permit farming or residential construction directly on top of a landfill. If, however, the reasonable assumption is made that 1 meter of soil covers the landfill, then the farmer's dose (from the same direct gamma and vegetation pathways Resnikoff considered[47]) is essentially zero – approximately 0.001 millirem per year – or about 100,00 times lower than the public radiation dose limit.[48]

5. Resnikoff's false claims regarding radium-related leukemia

Summary*: Resnikoff claims that leukemia can be caused by the inhalation or ingestion of radium-226. The radium-226 epidemiologic studies show that Resnikoff's claim is false.*

Resnikoff's lack of formal training in radiobiology is reflected in his incorrect

---

[45] This statement is based on a very conservative (exaggerated) calculation using the Argonne National Laboratory RESRAD Program (Version 6.4) – the same program used by Resnikoff. The calculation assumes a shale cutting radium-226 concentration of 20 pCi/g; a shale cutting density of 2.5 g/ml (from "Review of mechanical properties of oil shales" at http://www.thefreelibrary.com/Review+of+mechanical+properties+of+oil+shales%3A+implications+for+...-a0199396812 accessed August 30, 2010); the worker is assumed to be standing 8 hours per day, 365 days per year, directly on top of cuttings, which have an area of 10,000 square feet meters and a depth of 5 meters. The dose would be approximately 70 mrem/y.

[46] RESRAD computer code (Version 6.4), Argonne National Laboratory, "Ingestion: Dietary" menu under "fruit, vegetable and grain consumption." The RESRAD code is available at: http://web.ead.anl.gov/resrad/home2/, accessed August 30, 2010.

[47] Resnikoff, at p. 7 of his report, did not include radon in the hypothetical resident farmer's dose, probably because the primary public dose limit of 100 millirem per year does not apply to radon. *See* "Evaluation of Guidelines for Exposures to Technologically Enhanced Naturally Occurring Radioactive Materials," National Research Council (1999), p. 147.

[48] The resident farmer RESRAD Version 6.4 calculation was made, assuming a radium-226 concentration of 20 pCi/g, default occupancy factors, 2.5 g/cc density for shale cuttings, cuttings were 10,000 square meters in area and 5 meters in depth. Cover material with a depth of 1 meter and default density were also assumed.

statement that ingested or inhaled "Radium-226 … can cause leukemia."[49] One of the leading toxicology treatises states that "[i]t is significant that no study has identified a statistically significant excess of leukemia after even massive doses of radium."[50] Exposure to enormous internal radium-226 doses have caused bone sarcomas and head carcinomas, but only at doses that were orders of magnitude higher than any potential dose associated with the disposal of Marcellus shale waste in landfills.[51]

6. Resnikoff's claims regarding radon gas generated at the landfills

Summary: *Resnikoff speculates – without supportive calculations – regarding the volume of radon that will be caused by the storage of shale cuttings in landfills. If, however, the radon impact is calculated, it is found to be insignificant. Further, the U.S. Nuclear Regulatory Commission considers outdoor radon doses to be negligible because of diffusing outdoor air currents.*

Resnikoff states that "the landfill will generate progressively increasing volumes of radon gas over time, much of which can be expected to escape uncontrolled." Resnikoff makes no effort to quantify the off-site radon dose, which is calculated to be extremely small – 14 millirem per year[52] – compared with the approximate 120 millirem that U.S. citizens receive each year from natural background radon exposure.[53] Furthermore, the U.S. Nuclear Regulatory Commission has explained that "because of [the] natural transport of radon gas in outdoor areas due to diffusion and air currents, doses due to radium in the soil are negligible."[54]

7. Resnikoff's erroneous statements about measuring radium-226 in shale cuttings

Summary: *Resnikoff incorrectly criticizes the use of gamma spectroscopy despite his own reliance upon the procedure in the past, and general acceptance of the procedure by pertinent federal government agencies.*

---

[49] Resnikoff report, p. 6.

[50] *Casarett & Doull's Toxicology – The Basic Science of Poisons"* (7th ed., 2008), p. 1063. *See also Radium in Humans – A Review of U.S. Studies,* R. Rowland (Argonne National Laboratory, Doc. ANL/ER-3, 1994), pp. 99 *et seq.*

[51] "Cancer Dose-Response Analysis of the Radium Dial Workers," D. Hoel and B. Carnes, Proceedings of the 9th International Conference on Health Effects of Incorporated Radionuclides with Emphasis on Radium, Thorium, Uranium and Their Daughter Products" (HEIR 2004), p. 169.

[52] This off-site radon dose calculation was made using the Argonne National Laboratory RESRAD-Offsite (Version 2.6) computer program. A landfill with an area of 10,000 square yards, a depth of 5 meters, and no cover was assumed; otherwise, default variables were accepted.

[53] "Health Risks from Exposure to Low Levels of ionizing Radiation" (BEIR VII, Phase 2), National Research Council (2006), p. 3; available at http://www.nap.edu/catalog.php?record_id=11340; accessed August 30, 2010.

[54] Federal Register, Vol. 62, No. 139 (July 21, 1997), p. 39082.

At page 9 of his report, Resnikoff criticizes the measurement of the radioactivity in shale cuttings because the radiological laboratory used gamma spectroscopy for analyzing the radium-226 concentration in the cuttings.[55] Resnikoff maintains that the radium concentration should have been determined using the radon emanation technique and that gamma spectroscopy should not have been used on solid material. Resnikoff himself, however, has relied upon gamma spectroscopy in litigation involving the analysis of radium in solid material.[56] Further, the New York State Department of Environmental Conservation has stated recently that the gamma spectroscopy procedure, which was used by the laboratory that Resnikoff criticized, is an acceptable method for analyzing the radium concentration in soil samples.[57] Finally, the "Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM)," which was developed by scientists from the United States Environmental Protection Agency, Department of Energy, Department of Defense and Nuclear Regulatory Commission, identifies gamma spectroscopy (using a germanium or sodium iodide detector) as the "typical" laboratory procedure for analyzing gamma-emitting radionuclides (*e.g.*, radium-226 and its progeny) in soil samples.[58]

8. Resnikoff's incorrect calculations regarding landfill entrance radiation detectors

Summary: *Resnikoff has acknowledged that his calculations regarding the electronic detection of radium-containing shale cuttings in trucks entering a landfill are wrong by a factor of 1,000. This section discusses some of the reasons that his calculations were incorrect.*

In his effort to demonstrate that proposed landfill entrance radiation detectors cannot detect truckloads of shale cuttings containing significant concentrations of radium-226, Resnikoff performed a calculation assuming that the only nuclide in the cuttings would be radium-226. Radium-226, alone, is a weak gamma-emitter; and, as

[55] "Radiological Survey Report – Marcellus Shale Drilling Cuttings," T. Rahon (April 2010), p. 4.
[56] "Radioactive and Toxic Chemical Contamination in the Martha Oil Field, Kentucky," M. Resnikoff and S. Waligora (*Ray et al. v. Ashland Oil Inc. et al.,* Civil Action No. 97-CI-222, Lawrence Circuit Court, Kentucky, September 28, 2007), p. 10 and Attachment E (Bates No. EXSW0200038). Attachment E of Resnikoff's report indicates that the analytic method was LANL ER-130 Modified, which employs gamma ray spectroscopy using a high purity germanium detector. *See* "Gamma-Ray-Emitting Nuclides in Environmental Matrices-Instrumental Method, Environmental Chemistry, Los Alamos National Laboratory (April 1993 revision).
[57] June 30, 2010 letter from New York State Department of Environmental Conservation to Edward Buhrmaster, Esq, p. 3.
[58] "Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM)," U.S. Environmental Protection Agency and other federal departments (NUREG-1575, EPA 402-R-97-016, December 1997), p. 7-21.

Resnikoff claimed, MicroShield computer program[59] calculations indicate that shale cuttings containing thousands of picocuries of radium-226 alone might escape detection, depending on the sensitivity of the landfill detection system. Radium-226, however, does not occur alone in the cuttings, as Resnikoff incorrectly assumed. The Department of Environment Conservation specifically stated that "it is unreasonable to believe that a significant change in the concentration ratio between radium-226 and bismuth-214 (a radium daughter with much more energetic gamma ray emissions) would result."[60]

The Department of Environment Conservation's statement is supported by the department's actual measurements of both radium-226 and bismuth-214 concentrations in Marcellus shale cuttings from vertical[61] wells. The concentrations of the two radionuclides were statistically indistinguishable[62] – refuting Resnikoff's speculation that "shale cutting will contain substantially more radium-226 than bismuth-214."[63]

Where radium-226 is in equilibrium with its daughters, MicroShield calculations indicate that very low concentrations of radium-226 can be detected in truckloads of shale cuttings by portal detectors. Even Resnikoff acknowledged in his June 30, 2010 letter to Gary Abraham that "Marcellus shale drill cuttings contain little uranium and mostly radium-226 *and its decay products*." This admission is consistent with the DEC findings referenced in the preceding paragraph that showed nearly identical radium and bismuth concentrations in Marcellus shale cuttings.

Resnikoff's detector sensitivity calculations are flawed. He based them in part upon the dose coefficients in U.S. Environmental Protection Agency Federal Guidance Report No. 12. Resnikoff made several errors as he relied upon this report. First, FGR No. 12 provides external effective dose-equivalent coefficients that are based on the old International Radiological Commission Report No. 26, rather than the newer ICRP Report No. 60.[64] Second, to the extent that Resnikoff was attempting to calculate the

---

[59] MicroShield radiation software, Grove Software, Inc. (Lynchburg, VA, 2010); available at: http://www.radiationsoftware.com/index.html; accessed August 30, 2010.
[60] June 30, 2010 letter from New York State Department of Environmental Conservation to Edward Buhrmaster, Esq, p. 2.
[61] Resnikoff's unsupported claim that the radium concentration is greater in horizontal well cuttings that in vertical well cuttings is discussed in the next section.
[62] DEC draft report, Table 5-2 ("2009 Marcellus Radiological Screening Data"), p. 5-30. The comparative concentrations in the Crouch C 4H well were radium-226 at 1.843 ± 0.573 pCi/g, and bismuth-214 at 1.743 ± 0.208 pCi/g; in the Blair 2A well, radium-226 at 0.872 ± 0.330 pCi/g and bismuth-214 at 0.779 ± 0.120 pCi/g.
[63] June 30, 2010 letter from M. Resnikoff to G. Abraham, p. 3: "When radium-226 is leached from the shale and bismuth-214 is not (because the former but not the latter is water soluble), it can be expected that shale cuttings will contain substantially more radium-226 than bismuth-214."
[64] The ratio of the ICRP 26 to ICRP 60 dose coefficients is approximately 0.95. *See "Radiological Toolbox,"* U.S. Nuclear Regulatory Commission website at http://www.nrc.gov/about-nrc/regulatory/research/radiological-toolbox.html; accessed on

exposure rate in microroentgens per hour, the exposure rate is not equal to the external effective dose-equivalent rate, as he assumes. The ratio of the external effective dose-equivalent rate to the external exposure rate in air has been determined at NORM sites to be 0.67 microrem per microroentgen.[65] Third, Resnikoff assumes at page 8 of his report that the density of the shale cuttings is 2.35 grams per cubic centimeter, but FGR No. 12 assumes a density of 1.6 grams per cubic centimeter, thereby decreasing the exposure or dose rate per gram by a factor of 0.68. Resnikoff admits in his June 30, 2010 letter that his calculations are off by a factor of 1,000, but he does not attribute this massive error factor to any of the mistakes identified above.

9. Resnikoff's unsupported claim that the radium concentration in horizontal well cuttings is greater than in vertical well cuttings

Summary: *Resnikoff claims that the radium concentration in shale cuttings from horizontal boreholes will be significantly greater than the radium concentration in cuttings from vertical boreholes. His claim is based upon the unfounded assumption that barium is a drilling mud additive used to produce gas from the Marcellus formation and that its use increases the radium concentration in the cuttings. In fact, however, the use of barium would be counter-productive and the Department of Environmental Conservation has reported that it is not an additive used or proposed for use in New York.*

Resnikoff contends that there will be a higher concentration of radium-226 in the cuttings from horizontal boreholes than in the cuttings from vertical boreholes.[66] The explanation Resnikoff provides for this supposition is that "barium is added to drilling mud pumped into a horizontal wellbore …."[67] This claim that barium will be used as an additive in the Marcellus shale drilling mud is inconsistent with the DEC draft environmental impact statement, which indicates that barium is not an "additive[] used or proposed for use in New York."[68] While barium is used in some drilling muds to increase their density, adding barium in the Marcellus shale formation would be counterproductive because it would cause plugging of the fractures in the shale.[69]

---

August 30, 2010 (compare external effective dose-equivalent coefficients using ICRP 26 and ICRP 60).

[65] "Assessment of Dose from External Exposure at NORM-Impacted Sites," A. Ansari *et al*., Health Physics Society (1966 Midyear Proceedings), p. 228.

[66] Resnikoff report, p. 1: "When drilling horizontal boreholes within the Marcellus shale formation, one expects to see much higher radioactivity in solid waste …."

[67] *Id.,* p. 10, paragraph 5.

[68] DEC draft report, Table 6-1 ("Comparison of additives used or proposed for use in NY, parameters detected in analytical results of flowback from Marcellus operations in PA and WV"), p. 6.21 (column 3), and footnote 12 on page 6-19.

[69] "Marcellus Gas Well Hydrofracture Wastewater Disposal by Recycle Treatment Process," ProChemTech International, Inc., available at http://www.prochemtech.com/Literature/TAB/PDF_TAB_Marcellus_Hydrofracture_Disposal_by_Recycle_1009.pdf; accessed on August 30, 2010. *See also,* "Technology

Barium certainly is found in the flowback fluid,[70] but its apparent source is the formation brine.[71] Resnikoff sets forth no evidence that the barium concentration in the brine in horizontal wells is greater than the concentration in vertical wells. Thus, Resnikoff's speculation regarding enhanced radium concentration in horizontal cuttings, whether due to barium added to the drilling mud (as he incorrectly supposes) or to its presence in brine and then flowback fluid, is unsupported.

Conclusion

Resnikoff has not demonstrated that he has sufficient training or experience in health physics (or any other scientific discipline) to properly analyze the impact of placing Marcellus shale cuttings in a landfill. It is particularly noteworthy that Resnikoff's radiation dose calculations and health physics opinions have been rejected by both a federal and state court. His dose calculations in this instance are based upon his mischaracterization of Marcellus shale cuttings and misuse of available data. He relies upon relatively weak information (*e.g.,* a poor-quality gamma ray log which he simply assumes to be representative of Marcellus shale), which he misinterprets, and essentially ignores more reliable evidence (*e.g.,* the actual measurements of radioactivity in the shale cuttings collected by the New York State Department of Environmental Conservation). The hypothetical resident farmer's dose that Resnikoff calculates is based upon absurd assumptions, including the production of fruits, vegetables and wheat from a field of infertile shale. Resnikoff misrepresents the health effects of radium inhalation and ingestion. He concedes that his radium detection calculations are wrong by a factor of 1,000. In sum, Resnikoff opinions are not reliable and they should be rejected.

---

Assessment: Pilot Testing: Pretreatment Options to Allow Re-Use of Frac Flowback and Produced Brine for Gas Shale Resource Development," D. Burnett (Texas A&M University Department of Petroleum Engineering, February 15, 2010): The high levels of barium … common in flowback water will readily form precipitates, scale, which would rapidly block the fractures in gas bearing formations required for economic gas production. Removal of these constituents to much lower levels is thus required for recycle of flowback water, or use of production water, as frac water." Accessed August 30, 2010 at: http://www.netl.doe.gov/technologies/oil-gas/publications/ENVreports/FE0000847_TSA.pdf.

[70] DEC draft report, Table 6-1 ("Comparison of additives used or proposed for use in NY, parameters detected in analytical results of flowback from Marcellus operations in PA and WV"), p. 6.21 (column 4).

[71] "Water Resources and Natural Gas Production from the Marcellus Shale," D. Soeder, U.S. Geological Survey: "The formation brines often contain relatively high concentrations of sodium, chloride, bromide, and other inorganic constituents, such as arsenic, barium, other heavy metals and radionuclides that significantly exceed drinking water standards" (*citing* "The Marcellus Shale – an old "new gas reservoir" in *Pennsylvania Geology,* Pennsylvania Department of Conservation and Natural Resources, Vol. 38, No. 1.) Accessed at: http://www.netl.doe.gov/technologies/oil-gas/publications/ENVreports/FE0000847_TSA.pdf on August 30, 2010.