Radioactivity in Marcellus Shale

Report prepared for

Residents for the Preservation of Lowman and Chemung (RFPLC)

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May 19, 2010

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1.0 Qualifications

Marvin Resnikoff is Senior Associate at Radioactive Waste Management Associates and is an international consultant on radioactive waste management issues. He is Principal Manager at Associates and is Project Director for dose reconstruction and risk assessment studies of radioactive waste facilities and transportation of radioactive materials. Dr. Resnikoff has concentrated exclusively on radioactive waste issues since 1974. He has authored or co-authored four books on radioactive waste issues. In June 2000, he was appointed to a Blue Ribbon Panel on Alternatives to Incineration by DOE Secretary Bill Richardson.

He is a 1965 graduate of the University of Michigan with a Doctor of Philosophy in Theoretical Physics, specializing in group theory and particle physics. Dr. Resnikoff is a member of the Health Physics Society.

He has researched and written reports on radioactivity in oil and gas operations for the past 18 years. He has conducted dose reconstruction studies of oil pipe cleaners in Mississippi and Louisiana and is continuing to work on personal injury cases involving former workers and residents at the ITCO and other oil pipe cleaning yards in Louisiana and Texas. He is also presently working on several land contamination cases in Louisiana, Texas and New York involving radiological contaminants. He has conducted radioactive dose reconstruction studies of oil pipe cleaners in Mississippi and Louisiana, and of ranch hands in natural gas operations in Texas.

2.0 Process of Oil and Gas Drilling and Production

Since much of this discussion took place at the Issues Hearing, on April 14, 2010 in Elmira, New York, we will be brief.

2.1 Drilling

A vertical hole is first drilled down to the Marcellus shale formation using a rotary drill. As the drill digs deeper into the earth, additional drilling pipe is added to the wellbore. These pipes, known as a drill string when connected together, are each approximately 30 feet in length and add weight to the drill bit as it drills further through a rock formation. In order for the drill bit to drill deeper into the earth, rock cuttings generated during the drilling process must be moved out of the way and brought to the well surface. Thus, a drilling fluid is circulated through the drill string and used to bring the rock cuttings to the well surface. Drilling fluid can be a liquid or a gas or a combination of the two. Most often drilling fluid is a mud-like liquid consisting of water, clay, and chemical additives, such as scale inhibitors and biocides. Barium is also added for weight, and radium sulfate may form as well. The exact composition of drilling fluid varies from well to well and for different underground rock formations. In the case of vertical drilling to the Marcellus shale formation, pressurized air is used as the drilling fluid: the horizontal leg through Marcellus shale involves a liquid waste or slurry.

Once the vertical hole reaches the Marcellus shale formation, the direction of the drilling is transferred to horizontal drilling through the Marcellus formation. Often, one horizontal well will produce a better oil or gas reservoir than multiple vertical wells, and thus it is beneficial to drill horizontally. Most of the natural gas in the region is found within the Marcellus shale formation; thus, it is more economical and efficient for energy companies to use horizontal wells to tap directly into the stratum. It was stated at the Issues Conference that the spill waste disposed of in Elmira is coming from horizontal drilling at the Fortuna site in Bradford County.

As drilling fluid is circulated through the drill string and back up to the well surface, it mixes with rock cuttings and formation water from the underground formations. Formation water is water that occurs naturally within the pores and fractures of underground rock formations. Depending on the exact geology of a rock formation, formation water may have been present when the rock originally formed. Uranium, a radionuclide present in the Marcellus shale formation, is not soluble in water, but radium-226, a progeny of uranium, is soluble in water and can become mobilized when formation water is brought to the surface with drilling fluid and drill cuttings. Due to its prolonged existence in an underground formation, formation water can become highly concentrated in radium-226 and other radionuclides.

During horizontal drilling, a liquid drilling fluid is used to circulate drill cuttings to the well surface. Again, this drilling fluid mixes with formation water that may be highly concentrated in radium-226 and other water-soluble radionuclides. Once the gas or oil reservoir is reached and drilling is completed, casing is inserted into the newly-drilled hole and cement is forced into the void space between the walls of the casing and the rock formation. Production tubing, through which oil or gas will flow, is then inserted into the casing.

2.1.1 Drilling Waste Management

There is a variety of drilling waste management methods employed at the drill site that separate liquid and solid wastes before their respective disposal. Two of the most common methods in Pennsylvania involve the use of separation pits and shale shakers.

Separation Pits – Drill cuttings are placed in a plastic-lined, unleveled containment pit where liquid (drilling fluid and formation water) separates from the drill cuttings and falls into one end of the pit. These fluids are pumped into a storage tank and later reused in the well hole or transported to a wastewater treatment plant. The drill cuttings are disposed of at a landfill.

Shale Shakers – Drill cuttings are also dewatered via shale shakers, large sieves used to separate solid drill cuttings from liquid wastes (Figure 1). Drilling fluid and its contained wastes are passed through a vibrating screen on the shale shaker. Liquid wastes pass through the screen and are collected in an underlying basin, whereas the solid drill cuttings are retained above the screen. The shale shaker removes approximately 80% of the total liquid, which is pumped to a storage tank and can be later reused in the well hole or transported to a wastewater treatment plant. The drill cuttings, coated with any remaining liquid waste, eventually fall off the vibrating screen and are collected and disposed of at a landfill. These drill cuttings can also be mixed with sawdust or oak bark chips, creating a woody fiber mass which is transferred to a landfill.

Figure 1. Shale Shaker on an Oil Rig

2.2 Production

Production is the process of extracting oil and gas from an underground hydrocarbon reservoir. Since the casing and the cement prevent access to the hydrocarbon producing zone, the casing and cement must be perforated before oil extraction begins. A special gun is used to set off shaped charges, similar to those used in armor-piercing shells, and puncture holes in the side of the casing and the cement so that the oil and gas can flow into the well (Figure 2).[1]

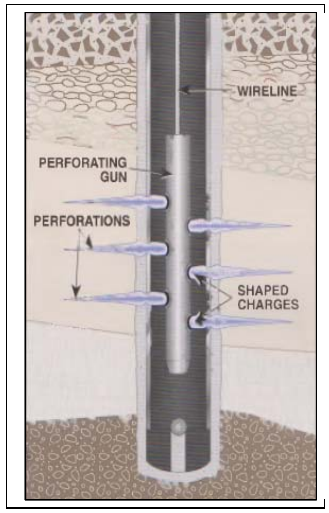

Figure 2. Perforations Created by Charges in a Perforating Gun[2]

As discussed above, formation water exists in the pores and fractures of underground formations, including hydrocarbon reservoirs found in such formations. Therefore, it is extracted from the formation with oil and gas as they are brought to the well surface. When produced water is brought to the surface, it carries with it dissolved solids and other compounds that may be present in the reservoir and rock formation, including Ra-226. Once the reservoir fluids are brought to the well surface, the oil, gas, and produced water are separated from each other. The oil and gas is then directed towards a pipe line, whereas the produced water is stored on site and later disposed of or injected into the underground formation.

3.0 Radionuclide Content of the Marcellus Shale

Radioactivity in the Marcellus shale results from the high content of naturally occurring radioactive uranium and thorium, their decay products including Radium-226, and radioactive potassium elements. The evidence of high radionuclide content is present in geochemical studies and in gamma-ray logs from wells drilled into the Marcellus formation.

In 1981 the United States Geological Survey performed a geochemical study of trace elements and uranium in the Devonian shale of the Appalachian Basin.[3] The Devonian layer refers to sediment formed 350 million years ago from mud in shallow seas. Its full profile consists of a number of strata as seen in Figure 3. Marcellus shale belongs to the Hamilton group of the Middle Devonian formation. Since the layers do not form in a line parallel to the ground surface, the depth at which Marcellus is found can vary from surface outcroppings to as deep as 7,000 feet or more below the ground surface along the Pennsylvania border in the Delaware River valley,[4] and as deep as 9000 feet in Pennsylvania.[5]

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[1] Baker, 2001

[2] Though Figure 2 shows perforation in a vertical leg, it is the horizontal leg in Marcellus shale that is punctured.

[3] Leventhal, 1981

[4] http://www.dec.ny.gov/energy/46288.html

[5] http://geology.com/articles/marcellus-shale.shtml

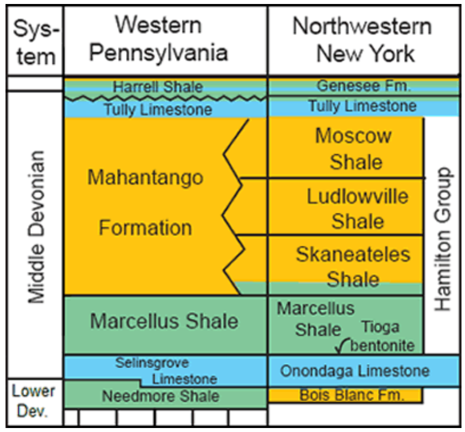

Figure 3. Stratigraphy of the Devonian Shale

The USGS study analyzed seventeen cores from wells in Pennsylvania, New York, Ohio, West Virginia, Kentucky, Tennessee, and Illinois. The researchers collected a variety of geochemical data to be used for resource assessment and identification of possible environmental problems. Rather than direct gamma spectroscopy employed by CoPhysics, uranium was measured in each core with a more appropriate and precise method, delayed-neutron analysis.

Although the cores varied in thickness and in depth, geologists identified the Marcellus stratum in several cores using data on the organic, sulfur, and uranium content of the samples. Table 1 summarizes the results from four cores that tapped into the radioactive Marcellus formation. The depths at which the layer was found as well as the uranium measurements are presented.

Table 1. Uranium Content and Depth of Marcellus Shale in Four Cores

Location of the Core	Depth of Sample (feet)	Uranium Content (ppm)
Allegheny, NY	7342 – 7465	8.9 – 67.7
Tomkins County, NY	1380 – 1420	25 – 53
Livingston County, NY	543 – 576	16.6 – 83.7
Knox County, OH	1027 – 1127	32.5 – 41.1

The four cores were taken from different geographical locations, but the characteristics of the identified Marcellus shale layer, specifically the layer thickness and high uranium content, are consistent. The thickness of the Marcellus shale formation varies between 0 and 250 feet, according to isopach maps. As seen in Figure 4, in Ohio and New York the Marcellus thickness is less than 100 feet, except in southeastern part of New York, where it is slightly greater.

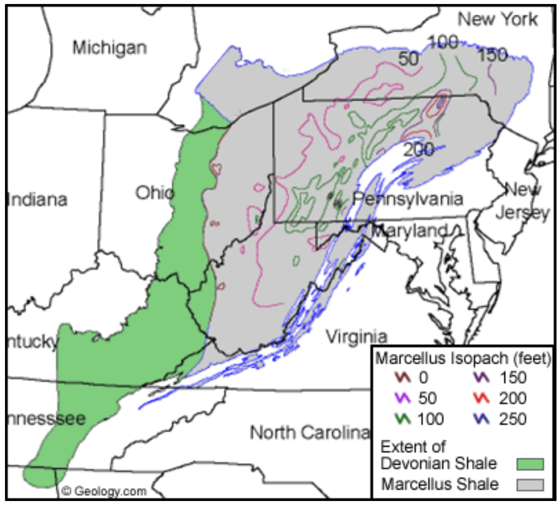

Figure 4. Thickness of the Marcellus Shale Formation

The thickness of the Marcellus layer in the four samples corresponds to the isopach map predictions and is approximately 123, 40, 33, and 100 feet (Table 1). Furthermore, the uranium content in the four samples is extremely high, as expected to be in Marcellus shale, and measures up to 83.7 parts per million (ppm), which is equivalent to 59.4 pCi/gram. Considering that the background uranium content in the four cores is approximately 4 ppm, or 2.8 pCi/gram, the radioactivity in the Marcellus is more than 20 times higher than background. Natural uranium radioactivity of 59.4 pCi/gram is attributed to uranium-234 and uranium-238, each of which contributes about 30 pCi/gram of radioactivity. Since Radium-226 is in secular equilibrium with U-238, it is also on the order of 30 pCi/g. These data show that the radioactivity of the Marcellus formation remains consistently high throughout.

In addition to geochemical studies, gamma ray drill logs also indicate high radioactivity in Marcellus shale. In fact, the Marcellus shale formation is *identified* using a gamma-ray detector that produces a chart of radioactivity (measured in GAPI units[6]) versus depth. Shale rock always displays a spike on such graphs, but compared to other shales the Marcellus shale formation spike is [7]substantially greater. The attached gamma-ray log (Attachment 1) shows a typical spike in radioactivity readings of >400 GAPI units, which is >24 pCi/gram and 25 times higher than background. This is consistent with DEC's findings for the radioactivity of Marcellus shale cuttings.

The gamma readings at the Marcellus shale horizon are uniform. The depth of the Marcellus shale varies, but the thickness of the formations and the uranium spike at all drill holes is remarkably consistent. We are confident that these are the radioactive levels measured in Marcellus shale.

4.0 Concentration of Radionuclides

As mentioned in Section 2 of this report, drilling fluid is used to remove the rock cuttings from horizontal wells in the Marcellus shale formations and to transport the drill cuttings to the well surface. The

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[6] The GAPI unit is defined by a calibration facility at the University of Houston, Texas, where pits with different mixtures of thorium, uranium, and potassium are located. The unit is defined as 1/200th of the deflection measured between the high and low activity zones in the pits. 16.5 GAPI units = 1 pCi/gram

[7] NYSDEC reported in their 2009 Draft Supplemental Generic Environmental Impact Statement (DSGEIS) radioactivities for rock cuttings from two wells in Lebanon and in Bath, NY, where the total radioactivity levels were 25.4+/-4.6 and 29.2+/-4.3pCi/gram respectively, which is consistent with these findings. These radium concentrations are far higher than background concentrations in New York State (Myrik1983),which is 0.85pCi/g.

recovered solid rock cuttings, suspended in a mixture of drilling fluid and formation water with elevated radionuclide content, are placed on shale shakers and dewatered before disposal in the County landfill. However, not all of the liquid waste in which the drill cuttings are suspended will be removed.

There are several steps in the Marcellus shale drilling process that allow radionuclides, particularly Radium-226, to concentrate in liquid waste. First, drilling fluids that include various chemical additives are artificially introduced into the borehole by high pressure injection. Drilling fluids are used during the drilling process to cool and lubricate the drill bit, prevent the well hole from caving in, and circulate drill cuttings to the well surface. Formation water, or natural brine, contained within the pore spaces and fractures of the rock, through which the drill bit progresses, can mix with the drilling fluid and be circulated to the well surface. The formation water can be contained in the rock formations for centuries and can contain extremely high levels of water-soluble radionuclides that are present in the underground formations. In addition to mixing with brine, the drilling fluid may also become contaminated when it comes in contact with radioactive rock. Radium-226 is a highly water-soluble radionuclide and will preferentially dissolve in the drilling fluid under the pressure and temperature conditions below ground. Drilling fluid can be reused many times and radium will progressively concentrate in it after each reuse. Since no sources specify the radioactivity of produced water, we assume that it is the same as brine, which NYSDEC measures at 15,000 pCi/L.[8]

During the Issues Conference NEWNY proposed to exclude from disposal at the Chemung County Landfill wastes containing liquids in excess of 20%. This liquid waste is likely to contain Radium-226 and other water-soluble radionuclides.

4.1 NYSDEC Permit

According to the draft permit, at Condition 31(b), free liquids, sludges, slurries, chemical or industrial wastes that are at least 20% solids can be disposed of at the County landfill. This means that up to 80% of wastes disposed of at the landfill can contain free liquid, sludge, or slurry.

As mentioned in Section 2 of this report, there are currently four possible methods for managing drilling wastes at a Marcellus shale drilling site. The three disposal methods utilized in Pennsylvania, and therefore most likely to be utilized in New York, involve the use of a shale shaker, well pad, or plastic-lined pit to separate solid drill cuttings from drilling fluid, which is highly concentrated with radium-226 and other radionuclides. Since drill cuttings are suspended in liquid drilling fluid upon entering a shale shaker, well pad, or plastic-lined pit, it would be impossible to remove all of the liquid material from the surface area of the cuttings. Drill cuttings particles are roughly the same size as coarse sand and, therefore, provide substantial surface area within a small quantity of particles. As a result, a considerable amount of contaminated drilling fluid will be disposed in the Chemung County landfill with drill cuttings.

5.0 Impacts of Contaminated Waste Disposal

Rock cuttings enhanced in Ra-226 and deposited in the County landfill will pose several problems, which were not considered by NYSDEC.

5.1 Landfill Soil Contamination

Radium-226 has a half-life of 1600 years and, if deposited in the landfill, will remain there essentially forever. Landfill workers that come in contact with the contaminated materials may be exposed. Further, if the landfill is ever inhabited in the future, crops grown in the soil will concentrate radium and be ingested. Ra-226 is a carcinogen and, when ingested or inhaled, concentrates in the bone and can cause leukemia. As we noted in our April 7 memorandum, at page 4, exposures to landfill workers and

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[8] NYSDEC, 2010, p. xxx

those who eat fruits or vegetables grown more than 1,000 years in the future over the closed landfill would exceed current health-based dose limits.

Our calculations show that the radiation dose from Marcellus shale drill cuttings, including the direct gamma dose, will exceed regulatory limits. Under the cleanup standards for land contaminated from inactive uranium processing sites, the EPA limits the concentration of radium within the top 6 inches of soil to 5 pCi/gram and to 15 pCi/gram at deeper depths.[9] Therefore, drill cuttings with concentrations of radium above 20 pCi/g (Table 1) would exceed these limits if deposited in a municipal solid waste landfill. Employing the standard Department of Energy software RESRAD, we find that radium concentrations of 20 pCi/g in soil lead to a direct gamma dose and ingestion of contaminated vegetation dose as high as 200 mrem/year. We assumed RESRAD default assumptions for a future resident farmer, including no earth cover in the landfill, a full-time resident, and a garden. Consumption of contaminated fruits and vegetables is the largest component of the dose.

5.2 Radioactive Leachate

Ra-226 is highly water-soluble and will dissolve in water under the temperature and pressure conditions present in the Marcellus shale formation and in water that is introduced into the well during the production process. The concentrations of radium in brine from the formation, or contaminated produced water, were measured by NYSDEC on the order of 15,000 pCi/L. Assuming that the Chemung County landfill accepts 2,000 tons of drill cuttings per week and that up to 20% of this waste is fluid, we estimate that up to 400 tons, or 40,000 liters, of contaminated water may be included in the waste. If we assume that this fluid contains up to 15,000 pCi/L of radium-226, then we calculate that 3.12E+11 picocuries of radium per year may be deposited into the landfill. Other assumptions may be reasonable, and the radium would not be released with leachate immediately, but we believe that NYSDEC has not adequately addressed the issue and has not completed a full analysis of the hazards presented by Chemung County landfill leachate when up to 2,000 tons per week of Marcellus shale cuttings waste is disposed in the landfill.

Several problems exist concerning contaminated liquid in the landfill. First, municipal waste landfills are lined with a layer of clay and plastic and are not designed to contain low level radioactive wastes. The leachate could mobilize radionuclides and distribute them in other locations throughout the landfill or potentially transport the radionuclides to groundwater sources outside the landfill in the event of a breach in the landfill lining. Second, the fluid will mix with leachate collected in the Chemung County landfill. This leachate with residues of radionuclides will be sent to the Elmira wastewater treatment plant, which, like the landfill itself, is also not designed to deal with radioactive waste. Radium-226 has a 1600-year half-life, so this is a long-term problem. Third, from the increasing inventory of radium-226, the landfill will generate progressively increasing volumes of radon gas over time, much of which can be expected to escape uncontrolled. As an inert gas, the landfill gas combustion device cannot control radon. Fourth, trucks transporting cuttings waste to the landfill will carry a substantial volume of liquid with the cuttings and therefore can be expected to leak on occasion. The leaking liquid is particularly radioactive and, over time, can be expected to contaminate local roadways and roadways inside the landfill site.

5.3 Radioactivity Detected by 375P-1000 Detector

Dump trucks transporting Marcellus shale drill cuttings from the drill sites to the Chemung County landfill will be monitored for radioactivity by a 375P-1000 radiation detector, manufactured by Ludlum Measurements Incorporated. These detectors will be placed approximately 6 feet from either side of the vehicles entering the landfill. According to Ludlum Measurements Incorporated, the 375P-1000 radiation detector will sound an alarm when it measures a radioactivity level that produces an exposure rate of 0.95 microCi per hour (μR/hr) above background radiation levels.

[9] 40 CFR Part 192.12.

We used the program MicroShield version 8.02[10], developed by Grove Software, to determine the minimum radioactivity (in pCi/g) of Marcellus Shale drill cuttings that would result in an exposure rate of 0.95 µR/hr and therefore sound the alarm of the 375P-1000 detector. MicroShield is a program used to estimate dose rates due to a specific external radiation source. The program allows its user to choose from sixteen different source geometries (such as a cylinder, sphere, disk, or rectangle) and up to ten different radiation shield geometries. MicroShield users may also choose custom source and shield materials from the MicroShield database, or design their own source and shield materials with the option of over thirty different constituents. When designing a source or shield material, MicroShield calculates the attenuation and build-up factors of all constituents.

We assume that all Marcellus Shale drill cuttings transported from the drilling sites to the Chemung County landfill will be transported in 15-18 ton dump trucks. We assume that the dump body of each truck body is approximately 12 feet in length, 4 feet in height, and 7 feet in width[11,12]. In addition, we assume each dump body is constructed with two steel side walls with an inner steel wall approximately 0.188 inch thick and the outer wall approximately 0.135 inch thick (10 gauge steel)[13]. Many dump truck bodies are equipped with two side walls so that any dents, scratches, or additional damage caused by the payload to the inner wall of the dump truck body will not appear on the outer surface of the truck.

As inputs to the MicroShield program, we believe the dimensions of the dump body are best represented by a rectangular prism with the same dimensions as specified above. We accounted for the double steel walls of the dump body by incorporating two individual stainless steel shields with thicknesses of 0.188 and 0.135 inch, respectively. We assume the dump body is completely filled with Marcellus Shale drill cuttings. We placed the 375P-1000 radiation detector six feet from the side of the dump body, as this would be the detector's approximate location in reference to all dump trucks entering the Chemung County landfill. The MicroShield program allows its user to manipulate the geometric shape of the radioactive source material, but the radiation dose receptor is always represented as a single point. Since the 375P-1000 radiation detector is not a point but a cylindrical tube with a height of 183 cm and a diameter of 20 cm[14], we assume that the height of the center of the 375P-1000 detector would be located at the same height as the center of the dump truck body and calculate the radiation doses that would be detected at the top, center, and bottom of the detector.

Shale is not a custom source included in the MicroShield database and we therefore designed our own source material to best represent the Marcellus Shale drill cuttings. We assume that the shale is comprised of mostly quartz (SiO_2) calcite ($CaCO_3$) and has a density of 2.35 grams per cubic centimeter (g/cm^3)[15]. Although Marcellus Shale drill cuttings will contain radioactive uranium-238 (U-238) and all of its gamma-emitting progeny, we only calculate the exposure rate caused by radium-226 (Ra-226). Ra-226 is soluble in water and will concentrate in any residual water transported with the drill cuttings into the dump truck body.

The MicroShield program calculates exposure rates, in millirads per hour (mR/hr), which result from the radioactivity of any given source. In order to estimate the radioactivity of Marcellus Shale drill cuttings based on exposure rates, we calculated the radioactivity of Marcellus Shale needed to produce an

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10 Grove Software Incorporated, 2008
11 Valew Truck Bodies, 2009
12 John Deere, 2010
13 Valew Truck Bodies, 2009
14 Ludlum Measurements Inc., 2009
15 University of Melbourne, 2003

exposure rate of 0.95 µR/hr. The relationship between external gamma radiation and exposure rates is linear. Based on the exposure rates of Marcellus Shale drill cuttings with Ra-226 concentrations of 50, 150, 500, and 1,500 pCi/g, we calculated that the Ra-226 concentrations in Marcellus Shale that produced a reading of 0.95 µR/hr are 2,340 pCi/g measured at the top and bottom of the 375P-1000 detector and 2,043 measured at the center of the detector.

As previously discussed, the County landfill will accept 2,000 tons of Marcellus shale drill cuttings with up to 20% of contaminated water. Since the rock cuttings and contained fluid is far less than the estimated sensitivity of the detectors, the radioactive scale cuttings, with up to 20% contaminated water, may not be detected.

6.0 Issues in the CoPhysics Report

The CoPhysics report, commissioned by Fortuna, concludes that the rock cuttings are only 2 to 3 times above background radioactivity levels.[16] However, they make several major mistakes in their methodology.

First, they claim the use of EPA 701.1 measurement protocol in their analysis. The EPA 701.1 protocol is a method used for gamma detection in radioactive materials dissolved in water and is not to be used for measurement of a solid. To measure the radionuclide content in a solid, the material must be dissolved in acid. Ra-226 is then chemically separated detected by measuring emanating radon.

Second, the CoPhysics study does not measure radium directly and instead measures a surrogate. For the detection of thorium-232, CoPhysics measures actinium-228, a decay product with strong gamma emission, which is acceptable since the two radionuclides are in secular equilibrium and since processing does not alter this equilibrium. However, this is not the case for radium, which selectively dissolves in fluid during the drilling process. Thus, use of bismuth-214 as a surrogate for radium-226 in the report is not permissible.

Lastly, it is not clear where the measurements were taken and whether any processing took place before the gamma detector readings. The CoPhysics report does not state whether the rock cuttings were taken from a horizontal or from a vertical bore hole. Under the temperature and pressure conditions that exist in a deep hole, the introduction of liquids into a horizontal well, enhances Ra-226. Since it was stated at the Issues Hearing that the Fortuna site in Bradford County uses horizontal wells, the study should have also analyzed rock cuttings from horizontal wells.

7.0 Conclusions

1. The hazard associated with the disposal of incompletely dewatered Marcellus shale drill cuttings and drilling fluid in a municipal landfill has not been fully evaluated by NYSDEC. The Marcellus shale has elevated radioactive concentrations, approximately 25-30 times above background concentrations. The drilling and dewatering processes enhance the concentration of radium in the drilling fluid. Rock cuttings that hold up to 20% of this fluid are still considered solid waste and will be disposed of in the County landfill. The introduction of this radioactive material into the landfill will give rise to serious problems due to the generation of radon, radiologically contaminated leachate and to potential reuse of the site in the future. NYSDEC regulations regarding the radiation doses from a decommissioned site and the allowable concentrations of radium in soil will be exceeded. In our opinion, these radioactive rock cuttings and associated radioactive drilling fluids belong in a radioactive landfill, such as the Envirocare landfill in Clive,

[16] CoPhysics Corporation, 2010

Utah. Radium-contaminated waste is similar to U mill tailings, which the Utah landfill is designed for.

2. Major uncertainties have not been resolved. The findings of the CoPhysics report conflict with borehole gamma readings and with the independent measurements of the USGS. The CoPhysics report does not explain where the cuttings were found and processed. The measurement methodology, EPA 701.1, and the use of a surrogate Bi-214 to measure Ra-226 are not appropriate for this case.

3. Worker exposure to radioactivity at the working face of a landfill that disposes such waste can be expected to exceed health-base dose limits set by EPA and NRC.

4. The waste at issue can be generated only by means of industrial processes in two gross phases: (a) fluids with chemical additives are forced into subterranean shale formations under high pressure, where they leach out NORM, making the fluids much more radioactive than they were before injection; solid waste is generated from the return waste water only by means of another set of industrial processes, including a shale shaker, centrifuge, and perhaps other mechanisms.

5. The drilling fluids that provide the source for the solid waste are chemically changed by pressurized contact with NORM, concentrating the NORM in the fluids. For example, barium is added to drilling mud pumped into a horizontal wellbore in order to extract radium sulfate from cuttings. This solid may be disposed of with the rock cuttings.

6. Based on RESRAD calculations, the radiation exposures received by a future resident farmer will exceed allowable regulatory limits. The radium concentrations in soil will exceed EPA regulatory limits. NYSDEC has not examined the environmental and health and safety implications of disposing of shale cuttings in a solid waste landfill. In our opinion, the radioactive scale cuttings and fluids are more appropriately deposited in a radioactive landfill designed for this disposal.

8.0 References

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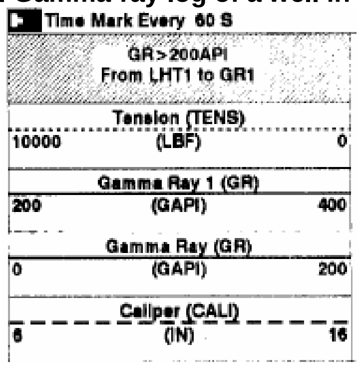
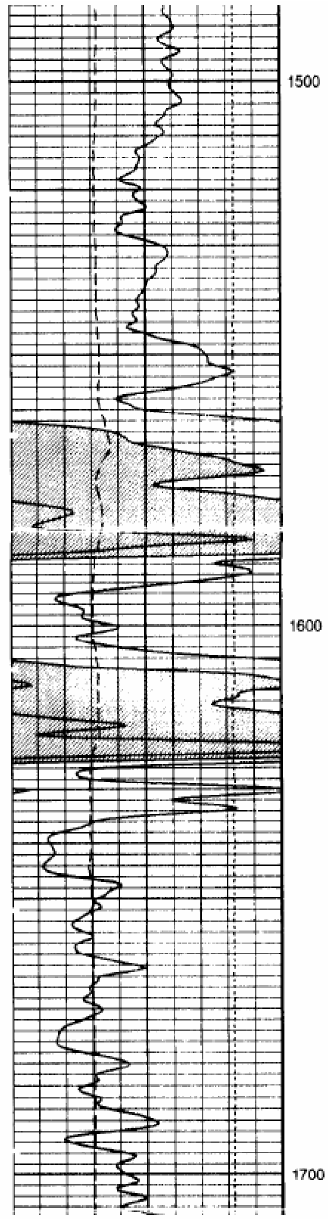
Attachment 1. Gamma-ray log of a well in Shiavone, NY

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1600
1700