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DEPARTMENT OF ENVIRONMENTAL CONSERVATION

Division of Solid & Hazardous Materials

An Investigation of Naturally Occurring Radioactive Materials (NORM) in Oil and Gas Wells in New York State

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GEORGE E. PATAKI, *Governor*

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PUBLICATION

AN INVESTIGATION OF NATURALLY OCCURRING RADIOACTIVE MATERIALS (NORM) IN OIL AND GAS WELLS IN NEW YORK STATE

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LIST OF ABBREVIATIONS AND ACRONYMS.

Bkg	background
BPR	former Bureau of Pesticides & Radiation, NYSDEC
cpm	counts per minute
DMN	NYSDEC Division of Mineral Resources
DSHM	NYSDEC Division of Solid & Hazardous Materials
GIS	Geographic Information Systems
HPGe	high purity germanium
<	less than
mrem/yr	millirem per year
NaI(Tl)	thallium activated sodium iodide
ND	not detected
NIST	National Institute of Standards & Technology
NORM	naturally occurring radioactive materials
NYSDEC	New York State Department of Environmental Conservation
pCi/g	picoCuries per gram
pCi/l	picoCuries per liter
pCi/ml	picoCuries per milliliter
psi	pounds per square inch
QA/QC	quality assurance/quality control
RESRAD	Residual Radioactive Material Guideline Computer Model
SPDES	State Pollutant Discharge Elimination System regulations
TAGM	Technical Administrative Guidance Memorandum
TNT	Thermo NUtech
USDOE	United States Department of Energy
USEPA	United States Environmental Protection Agency

DEFINITIONS

Absorbed Dose: The energy imparted by ionizing radiation per unit of irradiated mass.

Alpha spectroscopy: A technique to identify and quantify isotopes based on their alpha particle emissions. It permits measurement of certain isotopes, particularly those higher on the uranium and thorium chain that are predominately alpha particle emitters.

Background Radiation: As used in this report, consists of cosmic radiation from outer space, radiation from the radioactive elements in rocks and soil, and radiation from radon and its decay products in the air.

Brine: Water saturated with, or containing a high concentration of salt; any strong saline solution containing sodium chloride or other salts as calcium chloride, zinc chloride or calcium nitrate, etc. Brines may occur naturally but may also be generated by the injection of water to the subsurface and the subsequent dissolving of naturally occurring salt deposits.

Collector Point: An area consisting of one or more tanks(vessels) that receives the oil production from several wells, located at some distance away from this central area.

Curie: A unit of radioactivity. A quantity of any radionuclide that undergoes an average transformation rate of 37 billion transformations per second. One curie is the approximate activity of 1 gram of radium.

Dose equivalent: The product of the absorbed dose in tissue, quality factor, and all other necessary modifying factors at the location of interest. The unit of dose equivalent used in this study is the rem.

Gas well drip: Equipment designed to remove small quantities of liquids from a gas stream.

Gamma spectroscopy: A technique to identify and quantify radioactive isotopes based on their gamma ray emissions.

Quality Factor: The factor by which the absorbed dose is to be multiplied to obtain a quantity that expresses the biological damage to exposed persons. It is used because some types of radiation, such as alpha particles, are more biologically damaging than other types.

Rem: Acronym of roentgen equivalent man. The unit of dose of any ionizing radiation that produces the same biological effect as a unit of absorbed dose of ordinary X-rays.

Separator: A closed steel vessel or tank having baffles and valves used to separate materials of different specific gravities.

Solution salt mining: A method of recovering salt from the subsurface by injecting water to dissolve the salt deposit and then pumping the resulting brine to the surface for processing.

Total Radium: The Ra-226 concentration plus the Ra-228 concentration in pCi/g or pCi/ml.

Wax: A term used loosely for any group of substances similar to beeswax in appearance and character and distinguished by their composition of the higher alcohols (no fatty acids).

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AN INVESTIGATION OF NATURALLY OCCURRING RADIOACTIVE MATERIALS (NORM) IN OIL AND GAS WELLS IN NEW YORK STATE

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I. EXECUTIVE SUMMARY

- *Introduction*

This report presents the findings of the New York State Department of Environmental Conservation (NYSDEC) that New York State oil and gas production equipment and wastes are not significantly contaminated by naturally occurring radioactive materials (NORM). The concentrations of NORM found on oil and gas production equipment and wastes pose no threat to the public health and the environment. The research and analysis supporting this conclusion were performed in 1996. Direct measurements of the radioactivity at well sites were performed. Samples of scales, sludges, sediments, soils, water, rock, brines, waxes, and oils were taken and analyzed by gamma spectrometry.

- *Background*

NORM can be found in many geological formations and may be brought to the surface during oil/gas drilling and abstraction. Once at the surface it may accumulate in scales and sludges on and within drilling and processing equipment. It may also accumulate in brines and sediments within holding tanks or ponds.

During the 1980's, elevated concentrations of NORM were found on oil and gas mining equipment in the North Sea and in the Southern United States (Escott, 1984). This discovery generated concern in the United States and Europe. Elevated NORM concentrations may subject oil and gas workers to unnecessary radiation exposure. Concern was also raised about public exposure to people through the recycling of radioactively contaminated equipment or from the application of radioactive brines to roads for snow and ice removal.

In 1990, the New York State Department of Environmental Conservation Region 9 office performed an initial survey to determine if elevated concentrations of NORM existed at any of 17 western New York State oil and gas wells or on the related equipment. Using Geiger-Mueller (G-M) detectors for the survey, no significant contamination (defined as more than twice background levels) was found. The State of Pennsylvania found similar results during a 1994 NORM investigation of oil and gas well waste.

However, since the 1990 New York State investigation was limited (no samples were taken and only a small number of sites (17) were visited), the former Bureau of Pesticides and Radiation (BPR) planned a more extensive survey for 1996. This survey included a wider representation of New York State gas and oil fields and took physical samples to determine the actual concentration of the radionuclides involved.

- *Radiological Sampling and Surveying*

The investigation was performed by the BPR with the assistance of staff from the Division of Mineral Resources (DMN) and the respective NYS DEC regional offices. The BPR staff made six different field excursions, each to a different geographic location, to sample and/or take selected survey instrument readings at a total of 74 oil and gas well sites. Sampling and limited radiological surveys were performed in the following counties: Madison, Erie, Genesee, Wyoming, Cattaraugus, Livingston, Ontario, Seneca, Cayuga, Tioga and Chautauqua. A total of 101 samples were collected by field staff for analysis at the BPR gamma spectroscopy unit in Albany, New York, and/or the BPR's contract laboratory. Samples included water, brines, separator pit sediments, pipe scales, soils adjacent to oil/gas operations, and scales and sludges from tank bottoms. Eleven soil and rock samples were taken from nearby areas to establish background concentrations. Twenty-nine samples were taken to search for oil well contamination, 59 to search for gas well contamination, and two samples were taken from a mixed oil and gas area.

Survey instrument readings were taken at well heads, pipe exteriors, tank exteriors, soil beneath drains and spigots, drainage pits, and ditches. The more efficient thallium activated sodium iodide [NaI(Tl)] detectors (with a 2"x 2" probe for most investigations, a 1"x 1" probe for the remainder) were used in lieu of the G-M instruments employed in the previous survey. For comparison, background readings were taken near each selected survey site.

- *Results*

Samples were analyzed for 10 NORM isotopes. Radium-226 (Ra-226) and radium-228 (Ra-228) were of primary concern as these isotopes, due to their relative solubility, have been shown to accumulate in oil/gas production equipment and wastes. Ninety-one percent (71 out of 80) of samples from oil/gas equipment and wastes showed radium concentrations that were within twice the background concentration of local soils and rock. Background concentrations were found to average around 5 pCi/g total radium. (Total radium is defined as the sum of the radioactivity of Ra-226 and Ra-228.) No comparative background values existed for brines, oils, and waxes. Therefore the concentrations were judged solely on their radiological effects. The nine exceptions - three at gas well sites and six at oil well sites - are discussed below.

Gas well samples included 43 brine (salty waters brought to the surface as a by-product of gas production), 10 scale, two sludge, two water and one soil sample. Only two brine and one scale sample indicated radium isotope concentrations that were greater than 5.0 picocuries per gram (pCi/g) total radium (pCi/ml for liquid samples such as brines). The brine radium results, 0.95 and 24 picocuries per milliliter (pCi/ml) for one sample, and 3.8

and 7.7 pCi/ml for the other (Ra-226 and Ra-228 respectively), pose no threat to public health or the environment. This conclusion is supported by an analysis of road disposal of the brine with the U.S. Department of Energy's (USDOE) Residual Radioactive Material Guideline computer model (RESRAD). The scale result, 11 pCi/g for Ra-226 and 3.8 pCi/g for Ra-228, also poses no threat to public health or the environment due to the low amount of scale deposited in gas plant piping.

The 29 oil well samples were of more diversified origin, including four brine, one scale, six sludge, eight sediment, one water, two oil, and six wax samples. (Wax, or paraffin, may coat the interior of some pipes as a consequence of oil abstraction.) No brine, scale, wax, or oil samples appeared elevated. No radium could be detected in the one water sample collected. However, three sediment samples and three sludge samples exceeded the twice background range for local soils (up to a factor of four greater). Such concentrations should not pose a public health threat or an environmental risk given their isolated locations and low quantities. Again the USDOE's RESRAD system was used to evaluate abandoned brine pits to confirm the negligible risk posed by the sediment and sludge radioactivity concentrations.

The survey instrument readings taken at well heads, pipe exteriors, tank exteriors, soil beneath drains and spigots, drainage pits, and ditches revealed no radioactivity more than twice background.

- *Comparison With Other Investigations*

The concentrations of NORM generated by New York State gas/oil production were slightly greater than those found in a 1994 Pennsylvania study of sediments in brine holding ponds. The analytical results from the Pennsylvania oil field wastes showed uranium and thorium chain isotopes to be present at concentrations no greater than 5 pCi/g. The amount of thorium found in this investigation was in approximate agreement with that of the Pennsylvania investigation. The amounts of radium isotopes were somewhat higher but, as stated above, neither in a location or in a sufficient quantity to pose a hazard.

The New York State NORM concentrations were significantly lower than the North Sea samples, which generated some concern (Smith, 1987; Waldram, 1988). Scale samples from the North Sea oil fields contained Ra-226 at concentrations between 2,000 and 30,000 pCi/g (New York State samples ranged from none detected to 11 pCi/g). Sludge samples contained Ra-226 from 100 to 1,300 pCi/g (from 0.2 to 7.4 pCi/g in New York State). Hence, the North Sea scale samples were more than two orders of magnitude greater, and the sludge samples more than one order of magnitude greater, than those found in New York State.

- *Discussion of Results*

NYSDEC Technical Administrative Guidance Memorandum (TAGM) 4003 recommends a maximum dose limit to the general public of 10 millirem per year (mrem/yr) above background for free release of a site following the cleanup of radioactively contaminated materials. Given the NORM concentrations identified in this report, there are no plausible exposure scenarios that will yield 10 mrem/yr dose rates at New York State oil and gas wells (see following section). In fact, 91 percent of sample concentrations did not appear elevated above and/or were indistinguishable from background. The low survey instrument readings (within twice background) are consistent with the sample concentrations taken from the sites. Hence, NORM contamination at oil and gas mining sites poses no threat to the public or the environment.

- *Disposal of Oil and Gas Well Wastes Containing NORM*

The wastes from oil and gas drilling operations may contain low concentrations of elevated NORM. Of these wastes, the highest concentrations of radium were found in brines. To determine if disposal methods of these wastes may be of concern to the general public, the BPR used USDOE's RESRAD modeling program. The modeling showed that the most common method of brine disposal in New York State, spreading it on the roads to control ice and snow, does not present significant doses to the public. This is true even if it is assumed that all brines contain the highest concentration of radioactivity detected. The resulting dose from this worst-case scenario was estimated at slightly less than 3 mR/year - well below the 10 mR/year standard presented in TAGM 4003. RESRAD modeling also showed that abandoned sludge and sediment pits (an unauthorized practice that nevertheless occurs) do not pose any significant dose to the public.

- *Conclusions*

While NORM-contaminated equipment has been a concern in North Sea oil well drilling, the results of this investigation show that NORM contamination of New York State equipment is insignificant. New York State well drilling equipment and wastes do not constitute a health risk for the State's residents nor present a potential degradation of the State's environment.

II. INTRODUCTION

A. Objective

The purpose of this report is to quantify the NORM contamination, if any, within New York State's oil and gas equipment and wastes. Early in 1996, New York State Department of Environmental Conservation Commissioner Michael Zagata expressed an interest in investigating oil and gas wells in New York State for radioactive contamination. His interest was spawned by the discovery of naturally-occurring radioactive materials (NORM) in scales and sludges associated with other states' oil and gas production. Despite the failure of early investigations in New York State to indicate an oil and gas NORM problem, further investigation was warranted because of the small number of sites evaluated and the lack of extensive sampling. Commissioner Zagata directed that the issue be thoroughly assessed during the 1996 calendar year. To fulfill that directive, this report presents and discusses the results of the investigation conducted during 1996.

B. Background and History

- *Oil and Gas Production in New York State*

New York State was one of the first states in which oil and gas wells were drilled and developed. In 1821, the nation's first commercial gas well was drilled in Fredonia, New York, providing gas to light the streets of the town. For over 35 years this well produced several thousand cubic feet of gas per day from Upper Devonian shales. The State's first oil well was drilled in Allegany County in 1860. Again, the principal gas and oil producing formations were Upper Devonian. Oil production peaked when 6,685,000 barrels of oil were produced in 1882. Since these beginnings, more than 60,000 oil and gas wells have been drilled in New York State (NYSDEC, 1988). Oil and gas drilling activity has occurred in 436 towns across 46 counties, primarily in central and western New York.

The New York State Department of Environmental Conservation's Division of Mineral Resources (DMN) estimates the 1997 total gas and oil production to be 16.2 billion cubic feet and 276,330 barrels, respectively. The top five gas producing counties are Chautauqua, Tioga, Erie, Cattaraugus, and Cayuga. The principal oil producing areas are located in Allegany, Cattaraugus, Chautauqua, and Steuben counties (NYSDEC, 1997). In relation to the rest of the country, it has been estimated that New York State ranks approximately 21st in total gas production (with about 0.1% of total domestic production) and approximately 28th in crude oil production (with about 0.02% of total domestic production). The leading gas producing states are Texas, Louisiana, and Oklahoma, together comprising about 75% of total production; the leading oil producers are Texas, Alaska, and Louisiana, together comprising about 65% of total production (USEPA, 1993).

Several geologic units produce oil and gas within New York State. These sedimentary formations range in age from Upper Cambrian to Upper Devonian. Today, operators continue to drill to units such as the Upper Cambrian Theresa, Lower Silurian Medina, and Upper Devonian Richburg formations in their search for commercial oil and gas accumulations. Gas or oil or possibly both are encountered at various depths in these formations. In each case, production involves tapping into these underground reservoirs and drawing off the gas or oil. A stratigraphic column of southwestern New York is presented in **Figure 1**, page 3.

- *Production Methods and Equipment*

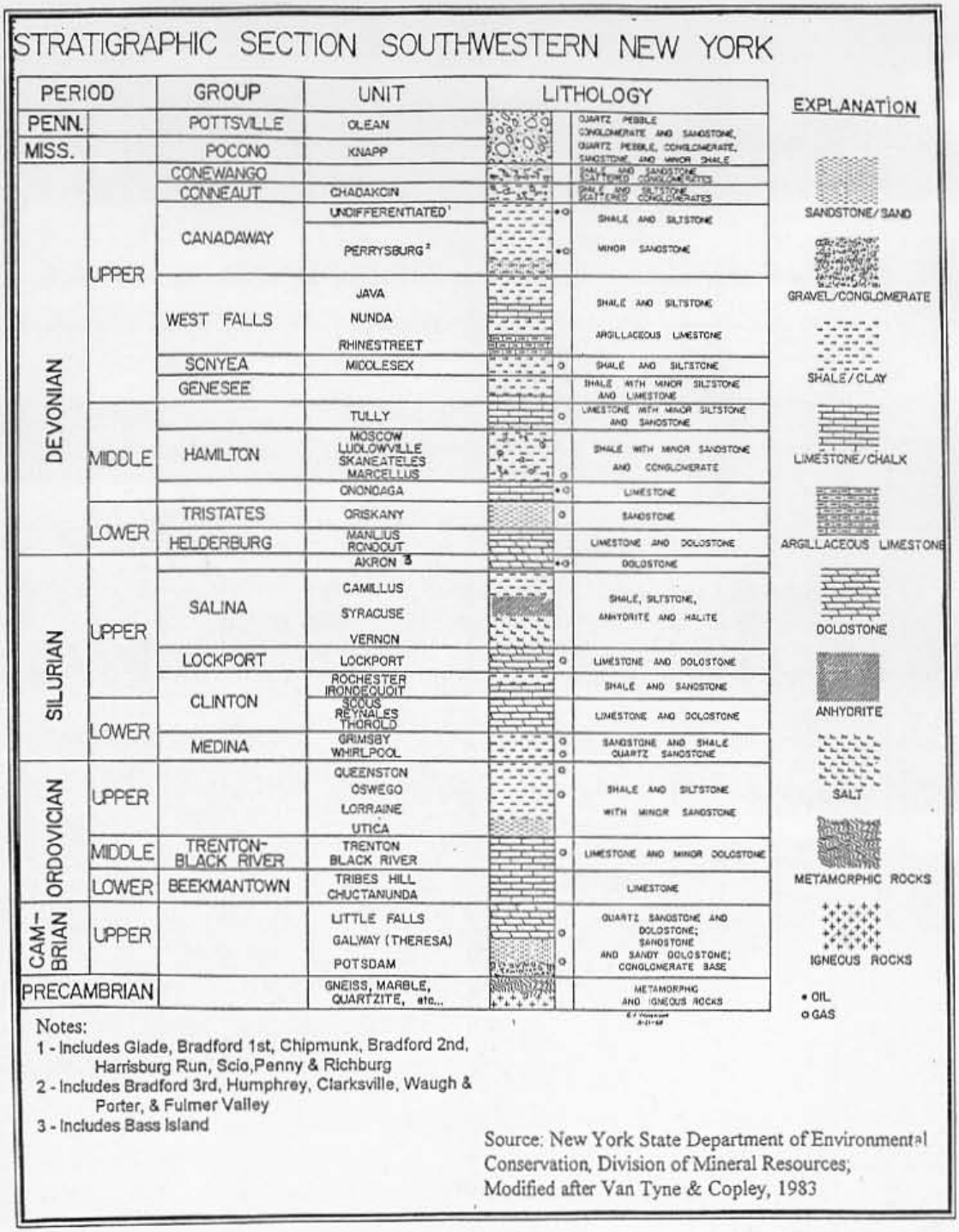
Gas wells in New York State are typically between 1,500 and 3,000 feet in depth, though some are as deep as 6,000 feet, and the gas is generally under normal formation pressure (1000-2000 psi). Production wells require surface casing to depths below the lowest potable groundwater source and usually have an inner casing extending to the gas bearing formation. The gas is dewatered at the surface through a pressurized separation unit. The gas is then directed into a gathering network while the separated waters, or brines, are diverted to a holding tank. Brines are salty waters which may be produced as a consequence of oil production, particularly when secondary production techniques are used. These techniques are described below. The tanks are periodically emptied by a commercial hauler. The brines are then frequently road spread for road compaction and dust suppression (dirt roads) in summer or for de-icing in winter.

Similarly, oil is usually produced by tapping into the underground oil reservoir with metal tubing. Unlike the gas wells, oil pressures are significantly lower and generally require pumps to bring the product to the surface. Sucker rod pumping, which uses a constant up and down motion of a rod and plunger assembly to create a suction in the pipe, is the most common removal technique.

In primary production, oil flows under natural pressure into the well bottom and then is brought to the surface. In secondary production, pressure must be added to the system to move the oil into the well bottom. The most common form of secondary production in New York State is the water flood method. This method uses water injection wells to increase pressure in the oil-bearing formations, consequently pushing the oil toward the production well. Eventually the injected underground water front depletes the oil in its path and reaches the production well itself. At this point, the well becomes unproductive (though it may become a water injection well), and a new oil production well must be constructed down gradient of the water front.

As with natural gas streams, oils may also contain brines, particularly oils generated from secondary production. During secondary production, injected water dissolves salts

Figure 1. Geological Strata of Southwestern New York



Notes:
1 - Includes Glade, Bradford 1st, Chipmunk, Bradford 2nd, Harrisburg Run, Scio, Penny & Richburg
2 - Includes Bradford 3rd, Humphrey, Clarksville, Waugh & Porter, & Fulmer Valley
3 - Includes Bass Island

Source: New York State Department of Environmental Conservation, Division of Mineral Resources; Modified after Van Tyne & Copley, 1983

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during its underground movement. During primary production, naturally occurring subsurface brines are brought to the surface as a byproduct of oil flow. The two are separated as a consequence of their different densities - oil tends to float over the brines. The lighter oil fraction, or product, is diverted into stock tanks for pick-up by a crude oil hauler. At newer wells, the brine fraction is diverted to a holding tank for eventual disposal, possibly by being spread on roads for dust control or road compaction. In the past, and at older wells, the separated brines were diverted to a settling pond or brine pit which discharged, or overflowed, into a nearby receiving stream. Many of these are still in use today, with the discharges, at some locations, under regulation via the Department's State Pollutant Discharge Elimination System (SPDES) permit program.

Estimates of brine production in 1987 for New York State oil and gas wells averaged about 8.6 million barrels. The vast majority of this volume (93%) was produced through secondary oil recovery. Of the total volume, 16% was recycled as a secondary production tool (the water flood technique), 63% was discharged under SPDES permit, and 17% was discharged to the surface. About 4% of the total volume was spread on public roads (Fitzpatrick, 1989).

Appendix B contains photos of typical New York State oil and gas wells and related equipment.

- *NORM as an Oil and Gas Issue*

NORM are an inherent part of many geologic materials. Consequently, NORM are encountered during geologically-related activities. During the 1980's, considerably elevated concentrations of NORM were discovered in oil and gas equipment associated with the North Sea drilling operations of the United Kingdom (Smith, 1987; Waldram, 1988). Subsequently, elevated radiation concentrations were discovered (1986) in some oil and gas equipment of the southern United States (USEPA, 1993). In these cases, the elevated NORM concentrations in the scales and sludges associated with used equipment were of particular concern. NORM contaminated equipment can lead to unnecessary exposures to workers during equipment refurbishing or reuse and/or the need for special handling and disposal procedures.

Many states with significant oil and gas mining activities continued to investigate these potential problems throughout the 1980's. A comprehensive survey and sampling program of oil and gas equipment residues was implemented by a number of states in cooperation with the American Petroleum Institute (API, 1989). NORM concentrations in oil and gas equipment were found to vary widely across the United States, from background for local soils and rocks to many times background concentrations (USEPA, 1993).

- *Previous NORM Investigations at Oil and Gas Wells in New York State*

In New York State, no investigation of oil and gas NORM contamination had occurred prior to 1990. Late in 1990, the Region 9 office (Buffalo area) of the NYSDEC conducted a field survey after an editorial appeared in the Buffalo News (December 5, 1990) concerning radioactivity in the oil and gas industry. Staff from NYSDEC's DMN unit in Olean surveyed equipment at 17 different oil and gas wells using a Geiger-Mueller (G-M) detector borrowed from the Cattaraugus County Health Department. The wells covered a range of geologic formations and extraction processes. The G-M detector revealed nothing above background levels at each location (Dahl, 1990). Additionally, NYSDEC staff determined via telephone interviews with individuals associated with oil and gas operations that scale buildup was not prevalent in the oil and gas industry in New York State (Merges, 1990). The negative G-M results and the limited scale accumulation in New York State oil and gas abstraction equipment suggested that NORM contamination was probably not an issue in New York State.

The 1990 survey conducted by Regional staff could not be considered conclusive. There is no existing documentation that the G-M meter used in the survey was properly calibrated prior to its use. Secondly, the 1990 survey was quite limited in scope and no samples were taken for analysis.

A 1994 investigation by the State of Pennsylvania (PDER, 1994) revealed relatively low concentrations of NORM isotopes in oil field sludge samples taken there. The observed concentrations were not sufficient to warrant public health or environmental degradation concerns.

C. Scope of 1996 NORM Investigations

In May of 1996, staff of NYSDEC's former Bureau of Pesticides and Radiation (BPR), Division of Solid and Hazardous Materials, began planning a comprehensive sampling program and an accompanying limited survey of oil and gas production equipment. Crucial to this planning was interaction and cooperation with staff from NYSDEC's DMN. The investigation was planned to cover a broad range of New York State wells including factors such as local geology, depth, and production quantity.

The survey team performed limited radiation surveys using a 2"x 2" thallium activated sodium iodide [NaI(Tl)] detector (for one trip, a 1"x 1" probe was used). In addition, radiation staff collected samples for spectroscopic analysis. This sampling was the primary focus of the work. Such samples included brines accumulated during oil and gas separation processes, water collecting in equipment or running off from the site following a rain, sediments from separator pits, scales from pipes, tanks, and separator units, and soils

around separator units and equipment yards. One hundred and one samples were collected. Seventy were analyzed on BPR's gamma spectroscopy system, and 40 samples were sent to the BPR's contract laboratory for radiological analysis - Thermo NUtech (TNT). Nine samples were analyzed by both laboratories.

III. PROCEDURES

A. NYSDEC/Industry Cooperation

The cooperation of certain oil and gas companies in the State was instrumental in assisting the NYSDEC to perform a thorough and comprehensive evaluation. The following oil and gas corporations assisted with the investigation: A.J. Lease/Fault Line Oil; Ardent Resources; Avoca Natural Gas Storage Project; BDH Oil Corp.; Belden and Blake; Cal-Ban Corp.; Chautauqua Energy; Oil, Gas and Land Services (OGLS); Kinley Oil Corp.; Lenape Resources; Meridian Exploration; Owens-Illinois (Dufco); Resource America; Seneca Resources; National Fuel; U.S. Gypsum; and Weil Resources. This assistance enabled the NYSDEC to sample gas and oil wells at a variety of well depths and locations.

B. Methods

Staff selected potential wells or associated areas in a given vicinity for sampling and/or surveying. Access to the area was obtained from the owners. Site visits included visual inspections, radiation surveys, and physical sampling of wells and areas of interest. Samples were then analyzed by gamma spectroscopy at the BPR laboratory or at a contract laboratory. Fourteen of the samples sent to the contract laboratory were also analyzed by alpha spectroscopy.

- *Selection of Sample and Survey Locations*

Potential sampling points were located by BPR staff using NYSDEC's ArcInfo Geographic Information System (GIS) database in concert with the DMN's Oil and Gas Well Database. The GIS database contains mapped indicators of the oil and gas wells in New York State. The DMN database provides information such as well status, depth, geology, dates of development, brine production, and owner. Using this information, staff selected wells from a variety of geologic formations, from different well depths within a given major producing horizon, and from a large geographic area. DMN regional inspectors and/or well owners helped identify appropriate sampling points.

- *Site Survey*

Field activities included limited radiation surveys at 113 sites, including nearly every site physically sampled, plus 26 others. These surveys were conducted at well heads, separator sites, and equipment yards. Instrumentation consisted of a 2"x 2" or 1"x 1" NaI(Tl) detection probe and rate meter. A 2"x 2" sodium iodide detector probe was used to survey all of the sites except those surveyed on excursion 4 (October 1996). During excursion 4, a 1"x 1" probe was used. While the 1"x 1" probe is less sensitive, it was the

only equipment available to staff at that time. The meters were calibrated against a Cs-137 standard. The radiation surveys, called here "area surveys," typically involved a walkover (with the detectors held within about 5 cm of the surface) of the areas approaching and adjacent the oil and gas equipment. The following were specifically targeted during the survey (with the meter held just above their surface): well heads, pipe exteriors and connections, tank exteriors and open portals, soil beneath drains or spigots, stained soils, drainage pits and ditches. "Background readings," taken to assess ambient concentrations, were taken at locations of 50 feet or more from well equipment or, in some cases, at roadsides prior to accessing the site right-of-way. All data were recorded in a field notebook.

- *Collection of Samples*

At most locations surveyed, samples were collected for later quantitative analysis. A total of 101 samples were collected. Sampling points were based upon professional judgement as to where NORM isotopes, if present, might settle out or accumulate. Background soil sampling points were selected from areas near enough to the oil or gas sites to be geologically similar, yet distant enough not to be impacted by the production operations. At gas well sites, 43 brine, 10 scale, 2 sludge, 2 water and 2 soil samples were collected. At oil well sites, 4 brine, 1 scale, 6 sludge, 8 sediment, 6 wax, 2 oil, 1 water, and 1 soil sample were collected. Two brine samples were of mixed oil/gas site origin. In addition, 11 background samples were also taken.

Samples were collected with the following procedures. Most liquid and sludge samples (almost all were from tanks) were collected with a plastic 300 ml cup attached to the end of a six- or 12-foot extension. When a tank was sampled, liquid samples were usually collected from the bottom. Soil and some sediment samples were collected with a clean garden trowel and usually pooled to form a composite of equal quantities from three points. Each of these samples consisted of a core of material from the surface to about four to six inches in depth. Pond sediments were collected with a one-inch diameter stainless steel coring device on an auger-extension bar. The corer collected bottom sediments to about four to eight inches in depth; at least three such samples were collected at each settling pond. All composite samples were mixed in a clean stainless steel bowl prior to filling the sample container. Sample containers were filled to a consistent level with the composite mix, after which the excess sample material was returned to the sample hole. The same individual collected all samples.

All samples, liquids and solids, were collected in 500 ml high density polyethylene containers. Sample containers were tightly closed and sealed with tape. The containers were labeled with the sample location, type of sample, date, time, field ID number and the initials of the collector. This information, along with field notes, was also recorded in the trip log. A list of typical sampling equipment is presented in Appendix C.

C. Summary of Field Trips

- *Areas Visited*

The areas of interest were surveyed and sampled over the course of six field trips. For practical reasons, each excursion concentrated upon wells in a particular geographic region. In many cases, regional DMN staff assisted in the coordination of site visits with owners. Details of each excursion and associated field work activities are recorded in the respective "Oil and Gas Trip Report" on file at the BPR's Albany office.

In mid-July 1996, BPR staff conducted its first excursion, visiting three active gas wells in Madison County. Radiation surveys of the gas well apparatus showed no significant readings above background levels. The following week BPR staff, escorted by Regional DMN staff, collected ten brine and soil samples at gas wells around the West Valley area of Cattaraugus County. Radiation surveys of the gas well apparatus showed no readings more than twice background levels.

In August 1996, BPR staff, working with DMN Regional staff and a representative of U.S. Gypsum, collected 32 samples from oil and gas well fields in Erie, Genesee, Wyoming, and Cattaraugus Counties, and from an equipment yard in Genesee County. Samples included brines, crude oil, scales from tank bottoms, oily sludge, pipe scale, sediments, and soils. Again, scanning of the various wells and apparatus with survey instrumentation indicated no readings above background.

In early October, 1996, BPR staff collected a total of nine brine samples from Genesee, Livingston, Ontario, Seneca, and Cayuga Counties. All survey measurements showed levels to be at background.

In late October and early November 1996, staff conducted a three-day sampling and limited radiation survey of oil and gas wells in Chautauqua and Cattaraugus Counties and a one-day excursion to Allegany County. During this time, staff visited approximately 23 well sites and three equipment yards, collecting a total of 39 samples. These samples represented three gas-producing formations (Bass Island, Medina, and Oriskany) and four oil-producing formations (Bass Island, Bradford, Chipmunk, and Richburg). All survey instrument results showed radiation levels to be at background.

Early in December 1996, BPR conducted a limited radiation survey and collected samples at two gas wells in the "Stagecoach field" (Helderberg Formation), Tioga County. This is a relatively young field (less than 10 years old), and pipe servicing and replacement has yet to occur. Consequently, no scale samples could be collected.

A general view of the areas visited during field activities is presented on the map in **Figure 2**, page 12. More detailed maps, indicating the locations of the survey and sample sites, are included as Appendix A. Exact sample locations are identified on the maps and in the plots contained in the trip reports (available at the BPR's Albany office).

- *Sites Surveyed and Samples Collected*

A total of 74 sites were checked with survey instruments and/or sampled during the six field excursions of this project. Most of these sites were wellheads and apparatus (68) although some were equipment yards (6). The sites were distributed within 13 different counties of central and western New York. The types of facilities visited and the numbers of counties represented are summarized in **Table 1** below. Nearly all of these facilities were actively producing oil or gas.

The total number of samples collected for analysis was 101. **Table 2** presents a summary of the types of samples collected and their distribution between oil and gas production. The reader may consult **Table D-1** (Appendix D) for a listing of the specific sites visited and a listing of the specific samples collected.

D. Geologic Formations and Site Information

Basic information about wells sampled and well owners was obtained from the DMN oil and gas well database and files. Additional information was obtained through discussions with DMN regional inspectors and interviews with owners, operators, and tenders of the wells. Some of this information (geologic formation and well depth) is presented in Appendix E as **Tables E-1** and **E-2**. **Table 3** presents a summary of the various geologic formations represented in the sampling program.

Table 1. Summary of Facilities Visited

Type of Facility	Number Visited	Number of Counties
Gas Well or Collector Point	48	12
Gas Well "Drips"	2	1
Combined Gas/Oil Well	1	1
Oil Well or Separator Site	16	3
Equipment Yard	6	3
Solution Mining	1	1

Table 2. Summary of Samples Collected

Type of Sample	Gas Related	Gas/Oil Related	Oil Related Primary	Oil Related Secondary	Background	Total
Brine	43	2	4	0	0	49
Scale	10	0	1	0	0	11
Sludge	2	0	2	4	0	8
Sediment	0	0	4	4	0	8
Oil	0	0	1	1	0	2
Wax	0	0	4	2	0	6
Soil	2	0	1	0	4	7
Rock	0	0	0	0	7	7
Water	2	0	0	1	0	3

Table 3. Summary of Geologic Formations Represented

Production	Formation	Number of Samples
Gas	Medina	40
Gas	Queenston	9
Gas	Theresa	4
Gas	Helderberg (Stagecoach)	2
Gas	Oriskany	2
Gas	Herkimer-Oneida	1
Gas	Rochester Shale	1
Gas	Akron	1
Gas/Oil	Akron (Bass Island)	1
Oil	Akron (Bass Island)	12
Oil	Bradford/Chipmunk	19
Oil	Richburg	4
Solution Mining	Salina-Vernon	2
Deep Disposal	Pre-Cambrian	3

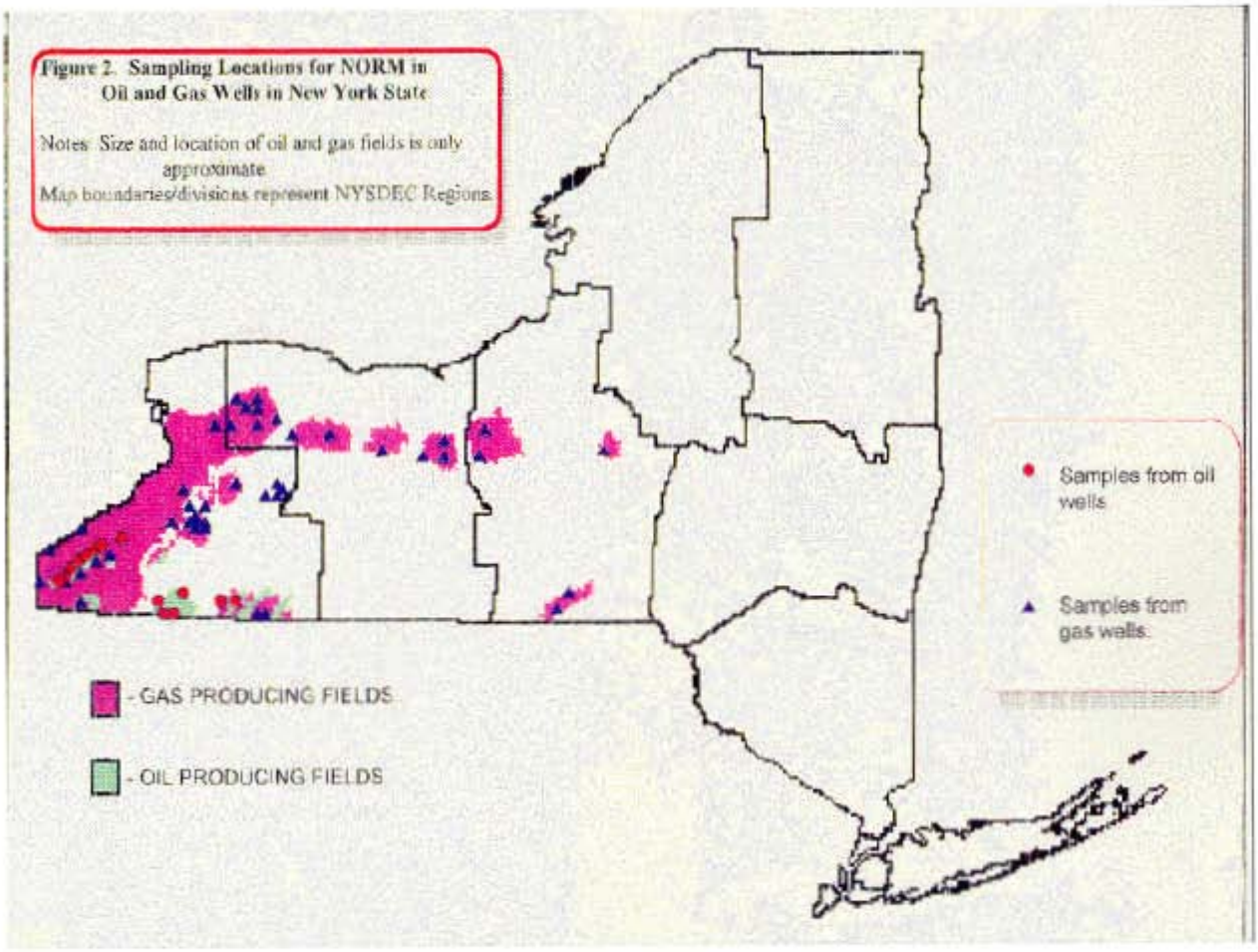


Figure 2. Sampling Locations for NORM in Oil and Gas Wells in New York State
Notes: Size and location of oil and gas fields is only approximate
Map boundaries/divisions represent NYSDEC Regions
Samples from oil wells
Samples from gas wells
- GAS PRODUCING FIELDS
- OIL PRODUCING FIELDS

IV. ANALYSES AND RESULTS

A. Site Survey Results

No significant increases in meter readings over background (defined as twice background) were observed at any of the sites. Background readings were taken near all gas and oil equipment surveyed. Such readings were at least 50 ft away from where the site measurements were taken, but still in the general vicinity of the site. In the vast majority of cases, the range encountered at a given location varied within a few thousand counts per minute (cpm) of 10,000 cpm. This is considered normal for background measurements of an area.

Radiation survey results are summarized by type of location in **Table 4. Table 5** contains a summary of the same results by geographic region (limited to those results observed with the 2"x 2" NaI(Tl) probe). A comparison of the two tables reveals that all levels are within the background range. Variations in local radiation readings probably relate more to geographic and geologic factors than to the facility type. For example, oil well fields tended to show higher readings than gas wells; however, the background levels tend to be higher in regions of oil development. Background readings were found to vary with geographic region and local surface formations, and as seen in **Table 5**, even within a county. For instance, local areas with bedrock outcroppings appeared to show higher readings than those with abundant soil and vegetation cover.

The entire listing of sites visited and sampled along with survey readings is included as **Table D-1** in Appendix D. Instrument quality assurance and quality control (QA/QC) procedures are included as Appendix F.

Table 4. Summary of Survey Instrument Results[†]

Type of Location	Detector Type	Range of Readings (cpm)
Background Readings	2x2 NaI(Tl)	5,000 -15,000
	1x1 NaI(Tl)	300 -500
Gas Well or Related Facility	2x2 NaI(Tl)	5,000 -17,000
	1x1 NaI(Tl)	250 -500
Oil Well or Related Facility	2x2 NaI(Tl)	8,000 -15,000
	1x1 NaI(Tl)	-
Equipment Yard	2x2 NaI(Tl)	8,000 -10,000
	1x1 NaI(Tl)	300 -500

[†] This chart represents an overall summary of all sites visited. Background and other measurements at individual sites had a narrower variation, high and low results were always within a factor of two.

Table 5. Background Radiation Readings (2"x 2" NaI(Tl) probe) and Geography

Geographic Region	Number of Readings	Range of Readings (cpm)
Genesee County	6	5,000 -10,000
Wyoming County	4	9,500 -12,000
Southern Erie/Northern Cattaraugus	7	9,000 -13,000
Chautauqua, Northeast of Lake	5	8,500 -11,500
Chautauqua, Southwest of Lake	5	8,000 -9,000
Southern Cattaraugus (Olean Area)	6	10,000 -15,000

B. Analysis of Samples

Seventy of the 101 samples collected were analyzed on the BPR Radiation Section's gamma spectroscopy system in Albany, New York. Forty samples were analyzed by the contract laboratory, TNT. Nine samples were analyzed by both laboratories. As will be seen from the following discussion, there were some differences between laboratories in sample preparation and analysis techniques.

- *BPR Sample Analysis*

Most soil samples and a few sediment samples were first dried. Dried samples were then covered securely and allowed to equilibrate for at least two weeks prior to counting. ("Equilibrate" means that the radium daughters were allowed to reach equilibrium: an equal decay rate of the elements in the decay chain from radium downwards.) Liquid samples were briskly swirled immediately prior to counting to resuspend settled solids and to enhance uniformity. All samples were weighed and the volumes determined for soil and liquid samples. Sample weights ranged from a low of 5 g to a high of 950 g, though most were between 300g to 700g.

For analysis of the samples, the BPR used a Canberra Nuclear High Purity Germanium (HPGe) Detector with a thin beryllium cryostat window. The system was calibrated with a National Institute of Standards and Technology (NIST) traceable multi-line gamma standard. This standard contains nine isotope gamma emissions spanning an energy range from 88 keV through 1836 keV. Its range covers the key energies of the primary radionuclides of NORM. Count times were either 30 or 60 minutes. The Canberra Series 90 multi-channel analyzer determined the energy of each gamma and the Canberra OmniGamma analytical software identified the radionuclide with peaks in the gamma spectrum. These results are reported in units of picocuries per gram (pCi/g).

Each printout was reviewed. In some cases, additional manual computations were necessary to distinguish between interfering nuclide peaks or to quantify nuclide peaks that the software detected, but could not identify. (Not every radioactive isotope is programmed into the computer to permit identification.) Correction factors for sample geometry and self-absorption were applied to each result. Results for liquid samples were converted to units of picocuries per milliliter (pCi/ml). Additional Quality Control (QC) measures included subtracting out system background, monitoring the calibration standard runs, and performing checks on the containers, water, and detergent used for sample collection.

- *Contract Lab Sample Analysis*

Forty out of the 101 total oil and gas well samples were sent to Thermo NUtech (TNT), of Oak Ridge, Tennessee, for gamma spectroscopy analysis. Of these 40, 10 were also analyzed by alpha spectroscopy and, for comparison purposes, nine underwent gamma spectroscopy at the BPR laboratory.

Sample preparation included mixing liquid samples prior to counting. Soil samples were first oven dried and then ground. TNT's gamma spectroscopy analysis consists of an eight-hour count time using Canberra's ProCount software, a VAX version based upon the Genie system used by the BPR. TNT's resolution was one channel/keV.

Alpha spectroscopic analysis, performed only by TNT, involves chemical preparation of samples. Liquids are preserved to a pH of 2 or less by acidification. They are mixed, heated with acids while partial evaporation occurs, and then run through an ion exchange column prior to counting. Solids are dried, mixed, and thoroughly ground to 100 mesh size, with a one gram aliquot used for sample preparation and counting.

TNT follows a laboratory Quality Assurance (QA) program that includes analyses of standards, spiked samples, blank samples and duplicate samples. The laboratory results from TNT report the nuclides as pCi/g (solids) or as pCi/l (liquids).

C. Analytical Results

- *Isotopes Analyzed*

One hundred and one samples were analyzed by gamma spectroscopy for nine distinct NORM nuclides - Ra-226, Pb-214, and Bi-214 of the uranium decay chain; Ac-228, Pb-212, Bi-212, and Tl-208 of the thorium decay chain; U-235 of the actinium chain; and K-40. Though not a NORM nuclide, the samples were also analyzed for Cs-137. The results for all but U-235 and Bi-212 are tabulated in **Table G-1** of Appendix G. The original laboratory reports are kept on file at the BPR office, 50 Wolf Rd., Albany, New York. The

U-235 information was dropped from the table because this isotope has not been associated with elevated NORM concentrations from oil production and gas plant equipment. Moreover, such results were likely inflated by the presence of radium-226 in the sample due to overlap of their gamma peaks. (For U-235 to be distinguished from Ra-226, sufficient U-235 must be present for it to be identifiable via one of its secondary gamma peaks. Sufficient U-235 was not present.) Likewise, the Ra-226 value would also be inflated by the presence of U-235 in the sample, but the results for Ra-226 were presented in the table to serve as an upper bound on the Ra-226 amount - an isotope of greater concern than U-235 due to its tendency to be concentrated during oil/gas production. The Bi-212 results are also in question due to its associated gamma peaks being difficult to distinguish from the peaks of other isotopes. Thus, the laboratory results for this isotope were dropped from the report.

Alpha spectroscopy was performed on 10 samples for seven different isotopes: U-238, U-234, Th-230 and Ra-226 of the uranium decay chain; Th-232 and Th-228 of the thorium decay chain; and U-235 of the actinium decay chain. Alpha spectroscopy primarily measures precursors of radium isotopes that are typically not brought to the surface by oil and gas production due to their relative insolubility. Though alpha spectroscopy does measure one radium isotope directly, Ra-226, the measurement was of limited value due to alpha spectroscopy's greater imprecision. Though alpha spectroscopy was used sporadically, it indicated that the chains were in disequilibrium - more radium was present than expected according to measured parent isotope concentrations. In 80% of the cases in which detectable amounts of Ra-226 and/or Ra-228 were present, the parent isotopes were at significantly lower concentrations, often differing by 1 -2 orders of magnitude.

- *Overview of Results*

Concern with NORM build-up during oil and gas abstraction focuses on radium isotopes. Due to their relative solubility over other isotopes in the thorium chain (Ra-224 and Ra-228) and uranium chain (Ra-226), radium isotopes tend to be "washed" to the surface during oil and gas production. Hence, radium isotopes and their progeny are the isotopes that may accumulate in oil and gas equipment and wastes and were the isotopes focused upon in laboratory measurements. Radioactive potassium (K-40), commonly found in soils, was also measured (Eisenbud, 1987). However, K-40 is not normally amplified by oil and gas abstraction processes (API, 1993). The Cs-137 concentrations are also not amplified by oil and gas abstraction processes, but the results were presented in Appendix G. Only trace concentrations of Cs-137 were found. The oil and gas well samples also analyzed by alpha spectroscopy indicated that few samples were in radioactive equilibrium, as expected. Radium isotopes and their progeny were disproportionately present. This matter is discussed in greater detail in Appendix G.

Most of the oil and gas well samples analyzed contained some detectable NORM constituents. Forty percent (six of 15) of the soil, sludge, and sediment samples from the oil well sites were at concentrations more than twice the average concentrations of nearby soils, but within an order of magnitude of background concentrations. The measured radioactivity of the oil and wax samples from oil well sites were at concentrations close to the detection limits of the instrumentation. The four oil well brine samples ranged from 0.650 - 1.6 pCi/ml for radium-226 and from 0.32 - 1.4 for radium-228. No radium at all could be detected in the water samples at either type of well site. The scale samples from gas/oil well site equipment, with one exception, were less than twice the average concentration of nearby rocks. At a gas well site, one scale sample of 10 sampled had a concentration six times greater than the background concentrations for rock in the area. This concentration was approximately 15 pCi/g total radium (Ra-226 concentration plus Ra-228 concentration). While no comparable background samples existed for the brine, two of the 43 brine samples taken from gas well sites were much greater than the others and were sufficiently high to warrant further investigation and analysis (one was greater than 25 pCi/ml total radium). Six of 29 samples collected at oil wells were more than 5 pCi/g total radium, and three of 59 samples collected at gas wells were more than 5 pCi/g, or 5 pCi/ml, total radium. These nine sample results receive a more detailed analysis below in the "Gas Well Samples" and "Oil Well Samples" subsections.

The final estimates for the radium isotopes were based on the higher of the available point estimates from the BPR and the TNT laboratories. It does not represent a true "worst-case scenario" presentation as the upper end of the error ranges was not added to the point estimates. Nevertheless, the presented results would tend toward conservative error due to this approach.

Table 6, page 22, is an overall summary, while the **Figures 3-9** on pages 24 -31 provide more detailed analyses. **Appendix G** contains all of the original data from which the tables and figures were constructed.

- *Background Samples*

Eleven samples fit the category of background in the respect that they were not impacted by oil and gas operations. Seven of these samples were rock and four were soil samples. The native soil samples indicated uranium decay chain radium concentrations of about one (0.8 - 1.1) picocuries per gram (pCi/g), thorium decay chain radium concentrations of 1.3 to 1.6 pCi/g, and radioactive potassium concentrations between 16 to 26 pCi/g (see **Figure 4**, page 26). These concentrations are typical for soils in New York State.

Seven rock samples from four distinct geological formations revealed concentrations of 0.2 to 2.4 pCi/g uranium (based upon Ra-226), 0.2 - 0.8 pCi/g thorium (based upon Ra-228), and 3.3 to 28 pCi/g potassium (see **Figure 9**, page 31). These concentrations are somewhat similar to those reported in Eisenbud (1987) which lists 0.4 - 1.3 pCi/g for Radium-226, 0.1 to 1.3 pCi/g for thorium, and 2 to 22 pCi/g for potassium in rock.

- *Gas Well Samples*

Fifty-six of the 59 gas well related samples tested showed NORM concentrations similar to background (considered as 1.8 pCi/g for uranium and thorium based on the background soil and rock samples collected as described above). Only three were of interest due to elevated NORM concentrations (see **Table 8**, page 23). One scale sample showed concentrations of Ra-226 at 11 pCi/g and Ra-228 at 3.8 pCi/g (see **Figure 5**, page 27). The other nine pipe scale samples were virtually free of NORM (scales are relatively uncommon in gas pipes). Two of the 43 brine samples also appeared elevated, but none of the water, sludge, and soil samples were elevated (see **Figures 4,6,** and **7**).

The 43 brine samples, the largest component of the 57 gas well samples, spanned the range, for the radium isotopes, from not detectable (ND) through about 24 pCi/ml (about 24 pCi/g). All but four brines were less than 2 pCi/ml for Ra-226 and Ra-228, or less than 2.5 pCi/ml for total radium. Only two appeared significantly elevated. One had a radium-226 value of 24 pCi/ml and a radium-228 value of 0.95 pCi/ml, the other a radium-226 value of 3.8 pCi/ml and a radium-228 value of 7.7 pCi/ml. These results are seen as clearly unusual from the other data in **Figure 3** (page 24). The highest NORM concentration, about 24 pCi/ml for the thorium chain radium value, is questionable because the uranium chain radium value was a factor of 25 times less . Normally one would not expect more than a factor of three or four difference between the two isotopes. Moreover, the actinium result, one of the most reliable estimators of the radium-228 quantity, pointed to a concentration of only 1.5 pCi/ml. Hence, an error in this reading is indicated. Additional samples will be taken from this well site to confirm this suspicion.

In the event that the elevated reading was not the result of error, the BPR used the RESRAD dose assessment model to construct a scenario involving road applications of brine to estimate the resulting dose to a member of the public. The scenario assumed a standard application rate of 1/3 gal/yd^2, two applications per each significant snow fall event (the standard practice in Chautauqua County, the only county that regularly applies brines to roads), and an average of 20 snow falls per year for 20 years. Given a stretch of dirt road with this scenario, the resulting application would be 13.3 gal/yd^2 per year or roughly 60 l/m^2. The scenario assumed no losses of radium due to erosion (highly implausible but worst case) and a direct pedestrian exposure of two hours per day, 300 days a year. Assuming an inhalation and direct ground hazard, the dose rates were calculated for the highest brine

result. For this reading, 0.95 pCi/ml Ra-226 and 24 pCi/ml Ra-228, the resulting dose after 20 years of application under this conservative scenario was estimated at 2.9 mrem/yr. For the second high reading, 3.8 pCi/ml Ra-226 and 7.7 pCi/ml Ra-228, the resulting dose was estimated as 1.7 mrem/yr.

Even given the "worst-case" assumptions cited above, the output from the RESRAD model showed that the dose rate upon the 20th year of exposure (the year of highest possible exposure) from all radium isotopes and its progeny would still be well below the NYSDEC TAGM-4003 cleanup guideline of 10 mrem/yr. This result was based upon conservative modeling and demonstrates that there is no reason to believe that the public health or the environment would be threatened.

- *Oil Well Samples*

Most types of oil well samples contained detectable concentrations of NORM nuclides with the exception of crude oils and wax. Only two samples of crude oil were tested, one from the Bradford formation and one from the Bass Island. Both were virtually NORM free. Similarly, six samples of paraffin (wax) were tested and found to have no more than trace concentrations of NORM (see **Figure 8**, page 30). The one water sample tested revealed no detectable amounts of radium.

Four brine samples from oil well separator or drain tanks were sampled and found to have a range of NORM constituents similar to the majority of gas well brine samples. While no background reference exists for brines, all four samples were less than 2.5 pCi/ml total radium (see **Figure 3**, page 24).

Sludge and sediment samples were the two categories of oil well samples that showed the highest radium concentrations. Three sediment samples and three sludge samples exceeded twice background concentrations (see **Table 7**, page 23, and **Figures 6** and **7**, pages 28-29). Three of six sludge samples had either Ra-226 or Ra-228 at concentrations higher than 3 pCi/g (ranging from just above 3 to 7 pCi/g). These three had total radium in the range of 6.9 -11 pCi/g, while two exceeded 8.0 pCi/g total radium. The sludges, which are primarily on tank bottoms, are generally isolated from the accessible environment.

Three of the eight sediment samples had total radium concentrations in excess of 5 pCi/g (range of 5.1 - 11 pCi/g). In each case, brines had either flowed (surface discharges of brine) or settled (brine pits or ponds) on the soils. However, neither the sludges or sediments are at high enough concentrations, or exist in sufficient quantities, to pose a hazard.

D. Comparative Analysis of Results

- *Comparison with Pennsylvania NORM Results*

In 1994, the State of Pennsylvania analyzed 23 sediment samples from brine pits associated with oil production. The brine pits were located in two different geological formations. The samples were each a composite of the top six inches of "mud" from three locations in a given pit. The analytical results from these Pennsylvania oil field wastes showed uranium and thorium chain isotopes to be present at concentrations no greater than 5 pCi/g. Thorium concentrations ranged from 0.8 -5.0 pCi/g, Ra-226 from 0.6 -1.8 pCi/g, and Ra-228 from 1.0 -1.6 pCi/g. The total radium reached concentrations no greater than 3 pCi/g (PDER, 1994).

The concentrations of NORM in New York State oil field wastes were found to be somewhat greater than those reported for fields in Pennsylvania. While the concentrations of thorium are in fair agreement with those found in Pennsylvania, the radium concentrations are higher. In the batch of eight New York State sediment samples, half (four) had total radium concentrations greater than any of the 23 Pennsylvania samples. However, this may be due to the rainwater dilution of the Pennsylvania pits. The New York State brine tanks were frequently covered.

- *Comparisons with North Sea Data*

As expected, the New York State NORM results were significantly lower than those reported during drilling operations in the North Sea, where the radium radioactivity of scales raised concern. Such scales contained Ra-226 at concentrations between 2,000 and 30,000 pCi/g, with Ra-226 in sludges at about 100 to 1300 pCi/g (Waldram, 1988). Results from the present New York State study showed maximum Ra-226 concentrations of 11 pCi/g in scale (outer scale on a pipe) and about 7 pCi/g in sludge. Thus, the New York State samples for scale and sludge are about a factor of 1000 and 100 less, respectively, than in the North Sea oil field samples.

- *Comparison of Radium and Potassium-40 Concentrations*

Potassium-40 (K-40) has not been found to be amplified by oil/gas production processes. Thus it serves as a reference point for the amplification of other NORM isotopes during oil/gas production. As evident on **Table 6**, the radioactivity of the naturally occurring isotope, Potassium-40 (K-40), is on par with, if not exceeding, that for the radium isotopes. Thus oil and gas production in New York State is not magnifying radium concentrations beyond that of background concentrations of K-40. Unlike radium, however, K-40 disintegrates without radioactive progeny and thus tends to pose less of a hazard. Nevertheless, USEPA's Residual Radioactive Material Guideline (RESRAD, version 5.61)

modeling shows that given the expected values from **Table 6,** the doses from the two radium isotopes would be similar to that received from the K-40 isotope. These results put the limited risk posed by the minimally elevated radium isotopes into perspective.

TABLE 6. SUMMARY OF ANALYTICAL RESULTS

Sample Type	Number of Samples	RA-226 Range (Uranium chain)	RA-228 Range (Thorium chain)	K-40 Range (Potassium)	Number Exceeding Total Radium Values of (in pCi/g or pCi/ml):		
					> 5	> 10	> 20
Gas Related Samples							
Brine (pCi/ml)	43	ND*-3.8	ND-24	ND-6.8	-	1	1
Scale (pCi/g)	10	ND-11	ND-3.8	ND - 70	-	1	-
Water (pCi/ml)	2	ND	ND	ND - 2.0	-	-	-
Sludge (pCi/g)	2	0.2-2.0	ND - 2.2	0.8 -1.0	-	-	-
Soil (pCi/g)	2	0.9-2.3	1.1-2.7	11-17	-	-	-
Gas-Oil Samples							
Brine (pCi/ml)	2	0.2 - 0.6	ND - 0.4	0.2- 1.0	-	-	-
Oil Related Samples							
Brine (pCi/ml)	4	0.6 - 1.6	0.3-1.4	0.7 - 2.4	-	-	-
Scale (pCi/g)	1	1.1	0.9	3.1	-	-	-
Sludge (pCi/g)	6	0.6-7.4	0.2-4.7	0.5-4.2	1	2	-
Sediment (pCi/g)	8	0.6-6.5	0.4-4.2	3.2-16	2	1	-
Wax (pCi/g)	6	ND - 0.2	ND - 0.2	ND - 2.2	-	-	-
Oil (pCi/ml)	2	ND	ND - 0.2	ND	-	-	-
Water (pCi/ml)	1	ND	ND	ND	-	-	-
Soil (pCi/g)	1	1.3	1.4	19	-	-	-
Background (Not influenced by Oil/Gas Processing)							
Soil (pCi/g)	4	0.8 - 1.1	1.3 - 1.6	16 - 26	N/A		
Rock (pCi/g)	7	0.2 - 2.4	0.2 - 0.8	3.3 - 28	N/A		

* ND - means concentrations were below the detection limits of the instrumentation. This concentration varied by isotope and by sample. However, if no radioactivity for that isotope could be detected, it can be assumed that no concentration above background was present

TABLE 6 NOTE: For ready comparison between values on the table, units of pCi/l were converted to pCi/ml. The latter is roughly equivalent to the radioactivity expressed as pCi/g and thus permits a more ready comparison. (One gram of water at standard temperature and pressure is equal to one ml of water).

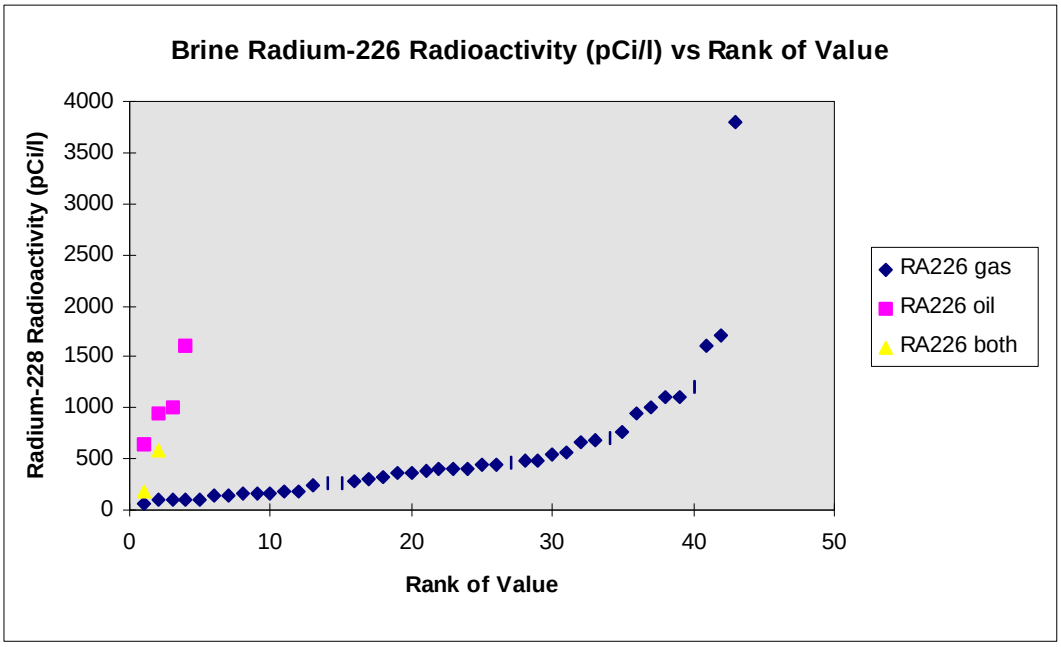
TABLE 7. OIL WELL SAMPLES EXCEEDING 5.0 pCi/g TOTAL RADIUM

SAMPLE TYPE	RADIUM-226 CONCENTRATION	RADIUM-228 CONCENTRATION
Sediment	6.5 pCi/g	4.2 pCi/g
Sediment	5.5 pCi/g	3.0 pCi/g
Sediment	2.8 pCi/g	2.3 pCi/g
Sludge	4.0 pCi/g	2.9 pCi/g
Sludge	7.4 pCi/g	4.7 pCi/g
Sludge	6.5 pCi/g	4.1 pCi/g

TABLE 8. GAS WELL SAMPLES EXCEEDING 5.0 pCi/g or pCi/ml TOTAL RADIUM

SAMPLE TYPE	RADIUM-226 CONCENTRATION	RADIUM-228 CONCENTRATION
Brine	0.95 pCi/ml	24 pCi/ml
Brine	3.8 pCi/ml	7.7 pCi/ml
Scale	11.0 pCi/g	3.8 pCi/g

FIGURE 3: OIL/GAS WELL RADIUM DATA FOR BRINES



OVERALL AVG:	599 pCi/l	OVERALL MAX:	3800 pCi/l
GAS AVERAGE:	567 pCi/l	GAS MAXIMUM:	3800 pCi/l
OIL AVERAGE:	1050 pCi/l	OIL MAXIMUM:	1600 pCi/l

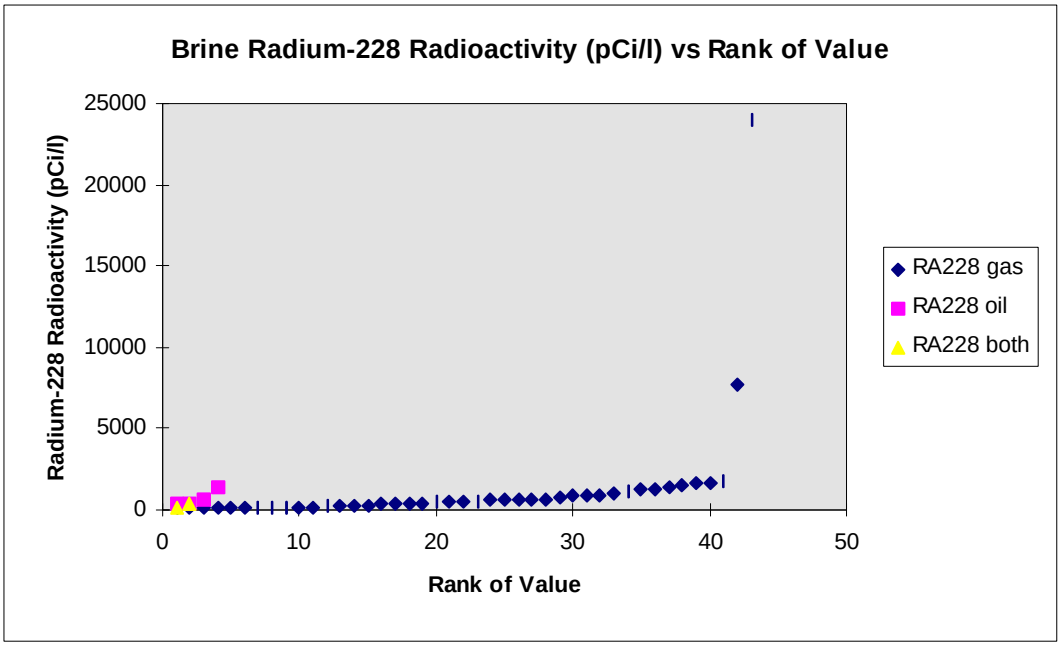
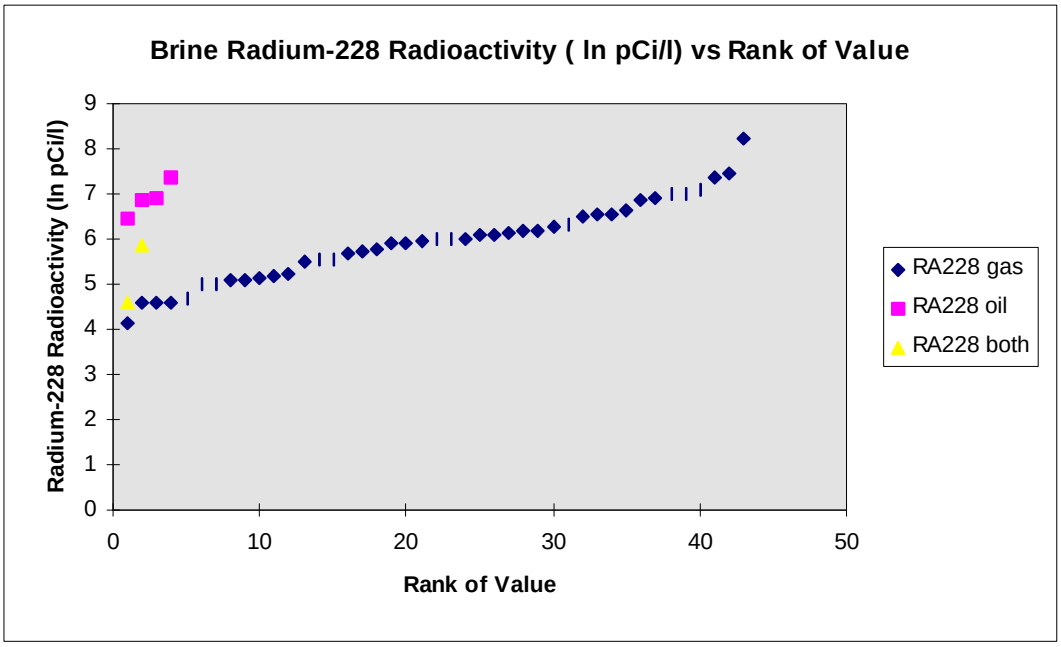
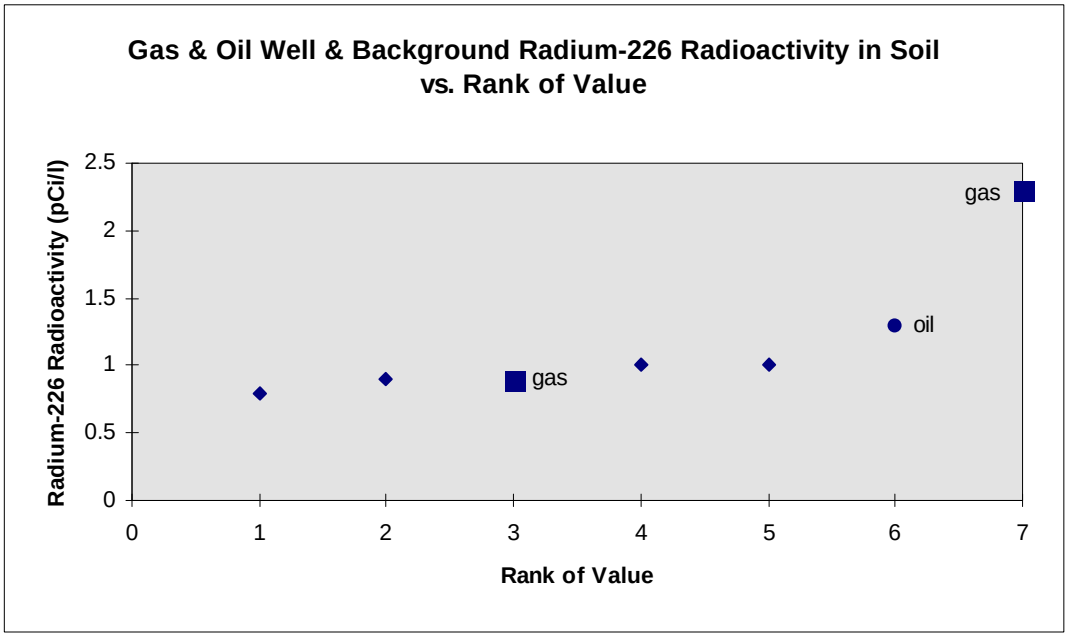


FIGURE 3 (continued): OIL/GAS WELL BRINE DATA IN LOGARITHMIC SCALE (RA-228 ONLY)

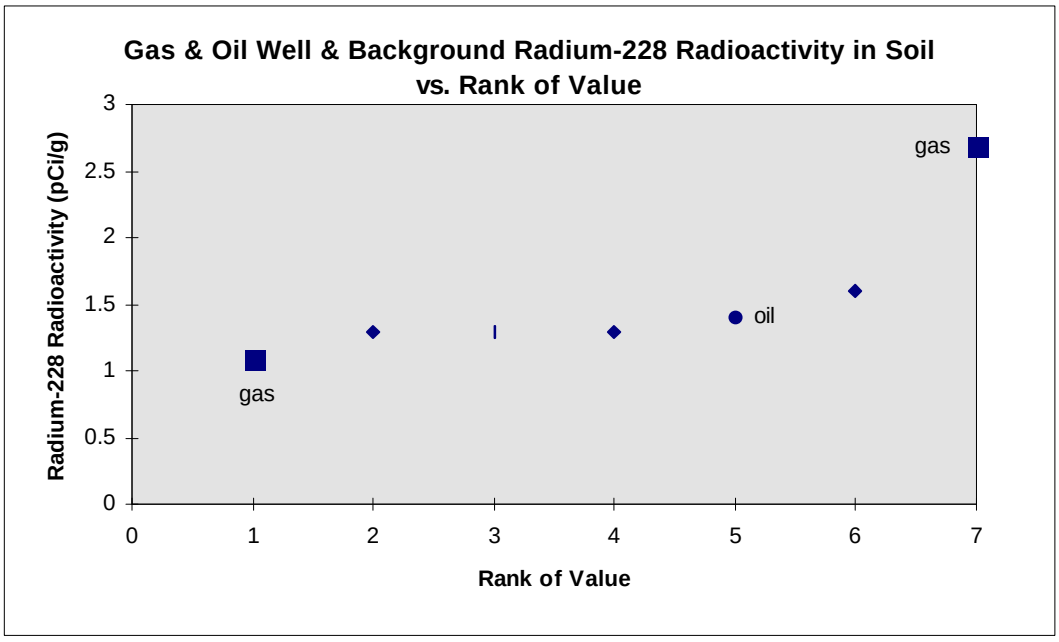


OVERALL AVG:	1222 pCi/l	OVERALL MAX:	24,000 pCi/l
GAS AVERAGE:	1316 pCi/l	GAS MAXIMUM:	24,000 pCi/l
OIL AVERAGE:	710 pCi/l	OIL MAXIMUM:	1,400 pCi/l

FIGURE 4: GAS/OIL WELL & BACKGROUND RADIUM DATA FOR SOILS

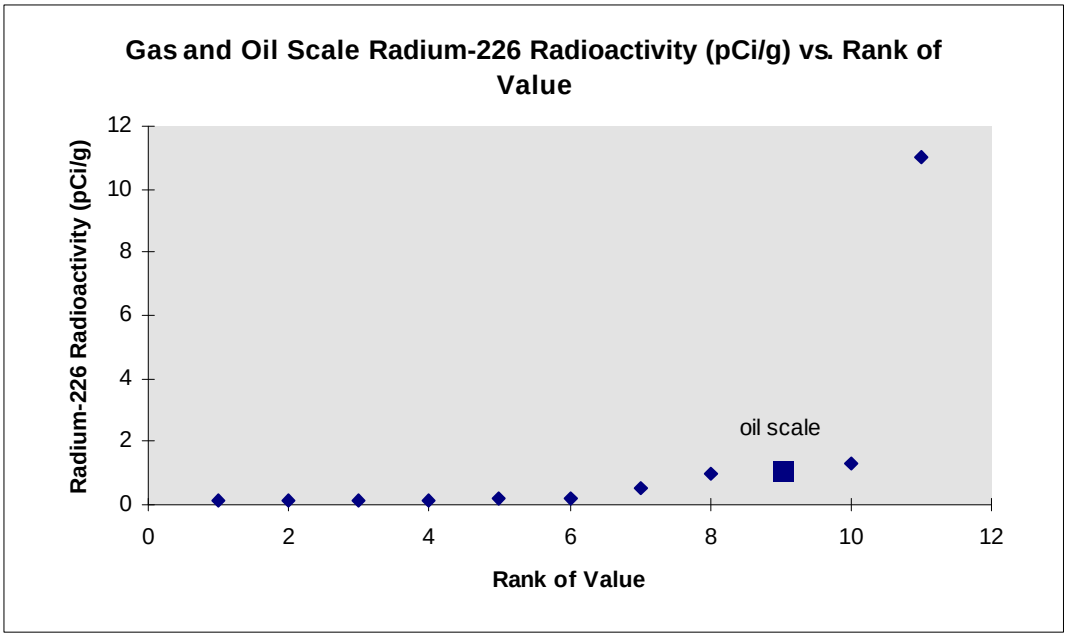


◆ BACKGROUND AVG: 0.9 pCi/g BACKGROUND MAX: 1.0 pCi/g
■ GAS WELL AVERAGE: 1.6 pCi/g GAS WELL MAX: 2.3 pCi/g
● OIL WELL SAMPLE: 1.3 pCi/g

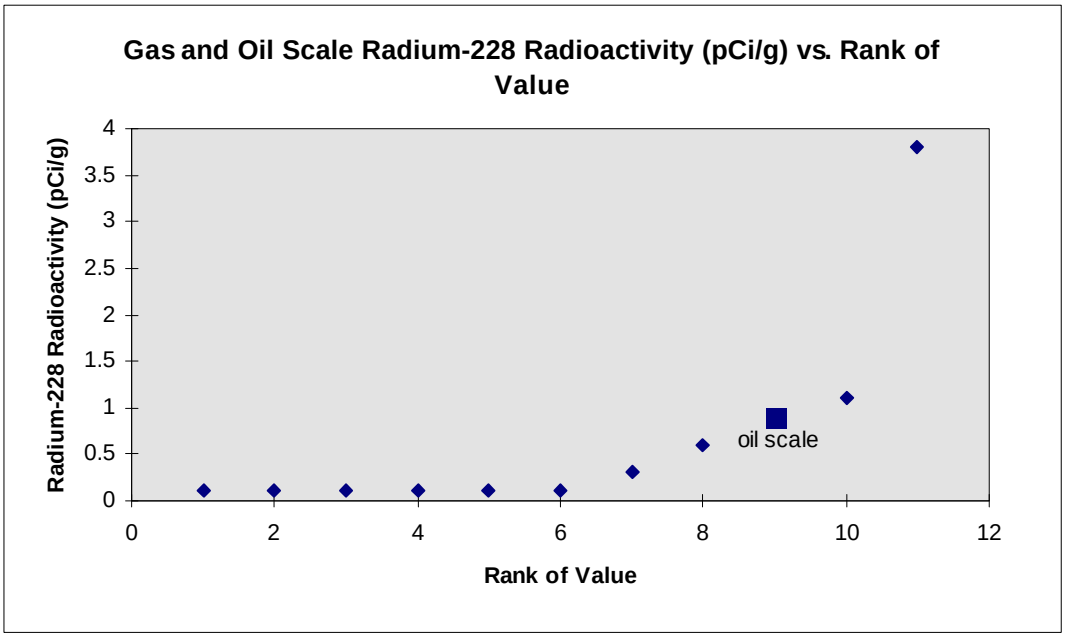


◆ BACKGROUND AVG: 1.4 pCi/g BACKGROUND MAX: 1.6 pCi/g
■ GAS WELL AVERAGE: 1.9 pCi/g GAS WELL MAX: 2.7 pCi/g
● OIL WELL SAMPLE : 1.1 pCi/g

FIGURE 5: GAS/OIL WELL RADIUM DATA FOR SCALES

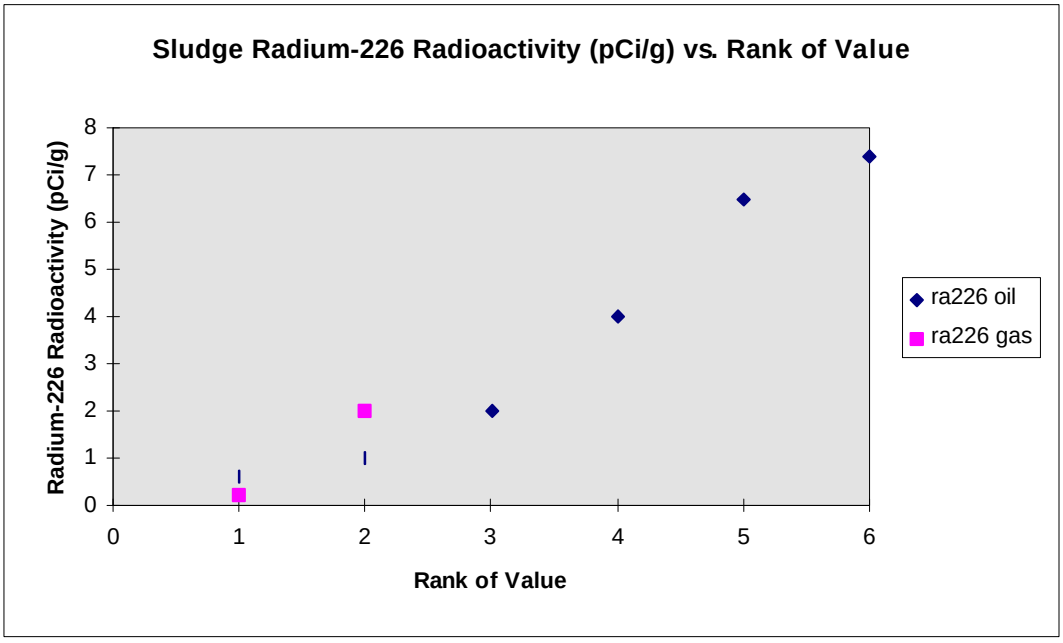


◆ GAS AVERAGE: 1.46 pCi/g GAS MAXIMUM: 11 pCi/g
■ OIL SAMPLE (only one) 1.1 pCi/g

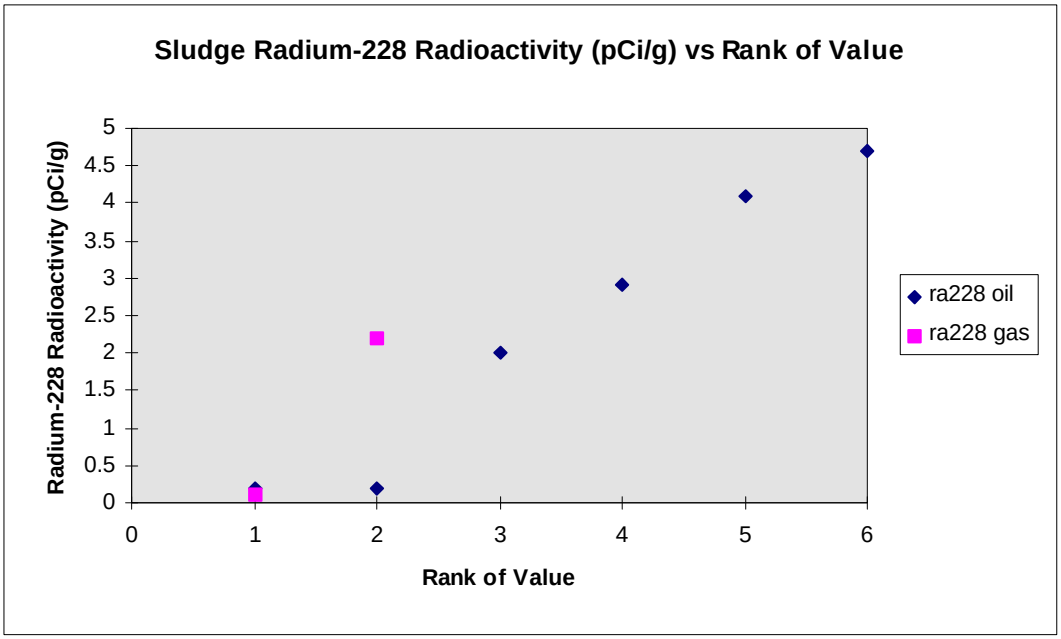


◆ GAS AVERAGE: 0.64 pCi/g GAS MAXIMUM: 3.8 pCi/g
■ OIL SAMPLE (only one): 0.9 pCi/g

FIGURE 6: OIL/GAS WELL RADIUM DATA FOR SLUDGES

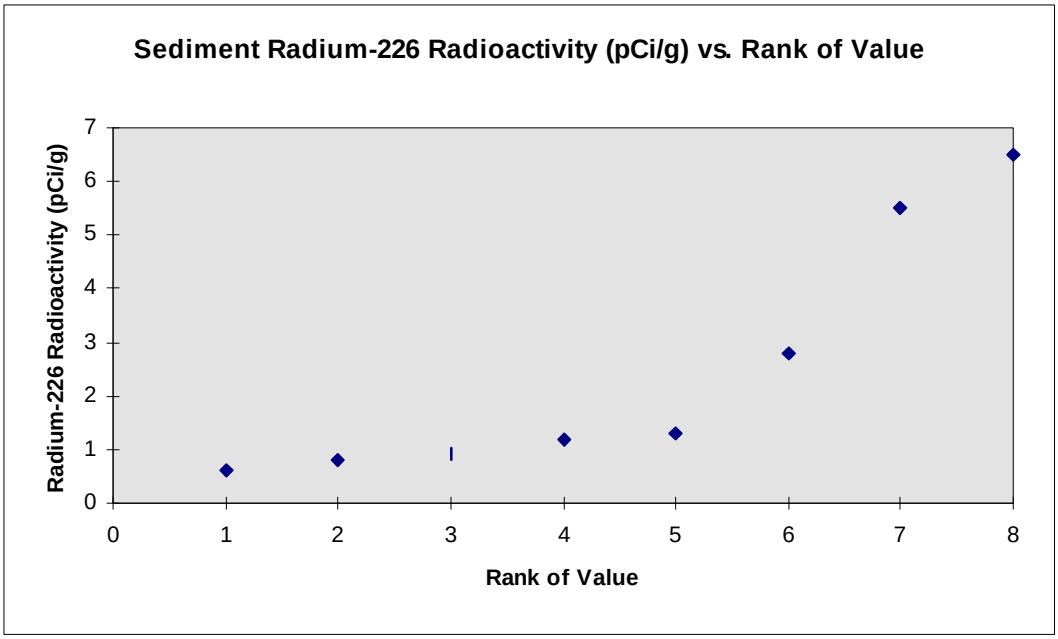


GAS AVERAGE: 3.6 pCi/g GAS MAXIMUM: 7.4 pCi/g
OIL AVERAGE: 1.1 pCi/g OIL MAXIMUM: 2.0 pCi/g

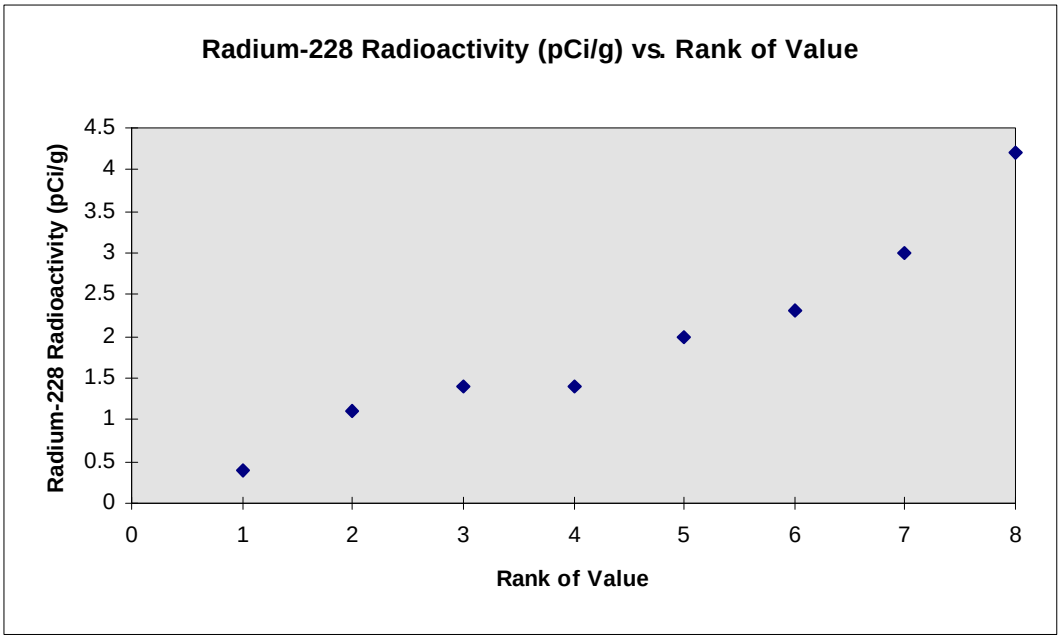


GAS AVERAGE: 2.4 pCi/g GAS MAXIMUM: 4.7 pCi/g
OIL AVERAGE: 1.2 pCi/g OIL MAXIMUM: 2.2 pCi/g

FIGURE 7: OIL WELL RADIUM DATA FOR SEDIMENTS

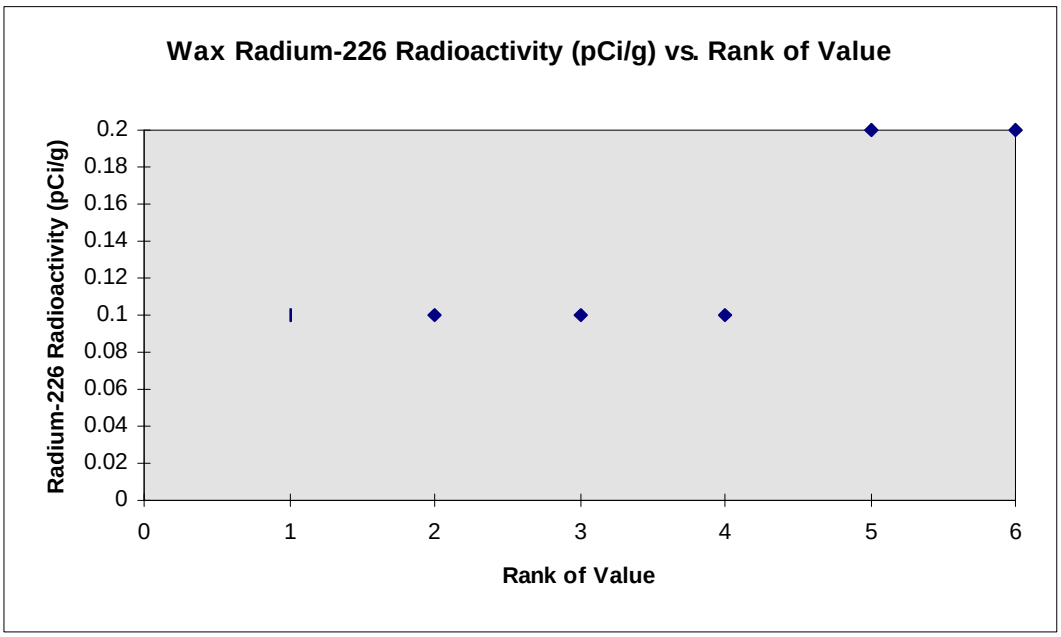


AVERAGE: 2.6 pCi/g
MAXIMUM: 6.5 pCi/g

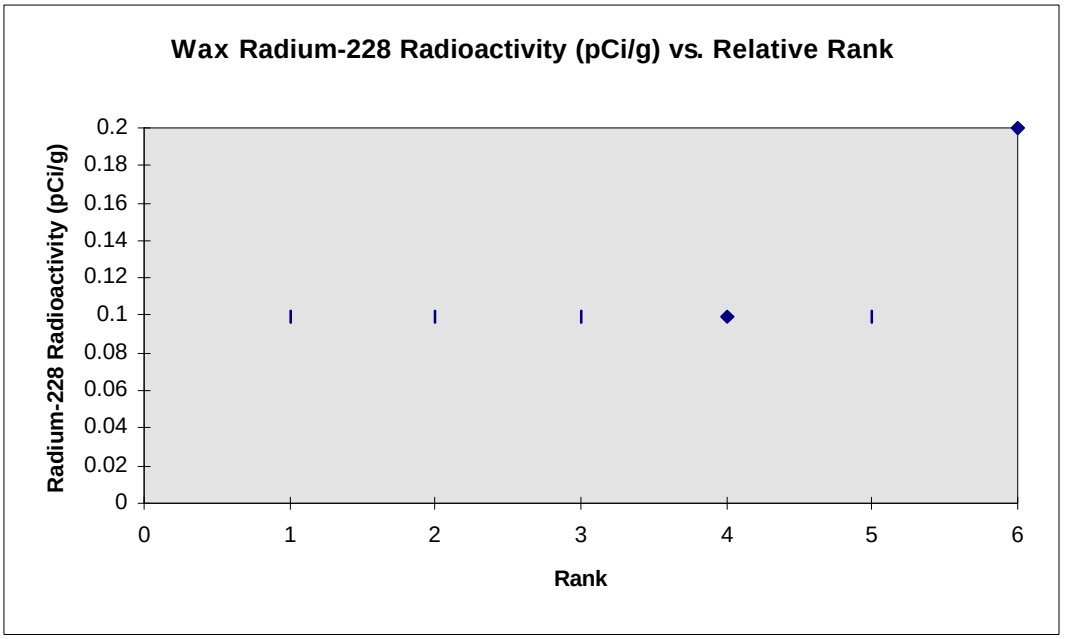


AVERAGE: 2.0 pCi/g
MAXIMUM: 4.2 pCi/g

FIGURE 8: OIL WELL RADIUM DATA FOR WAXES

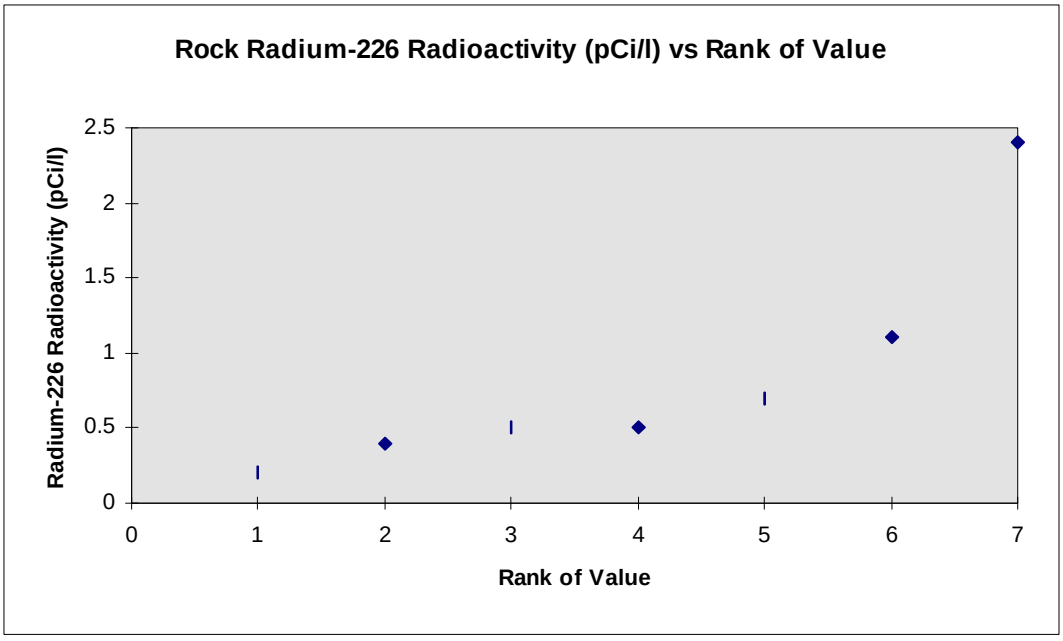


AVERAGE: 0.13 pCi/g
MAXIMUM: 0.20 pCi/g

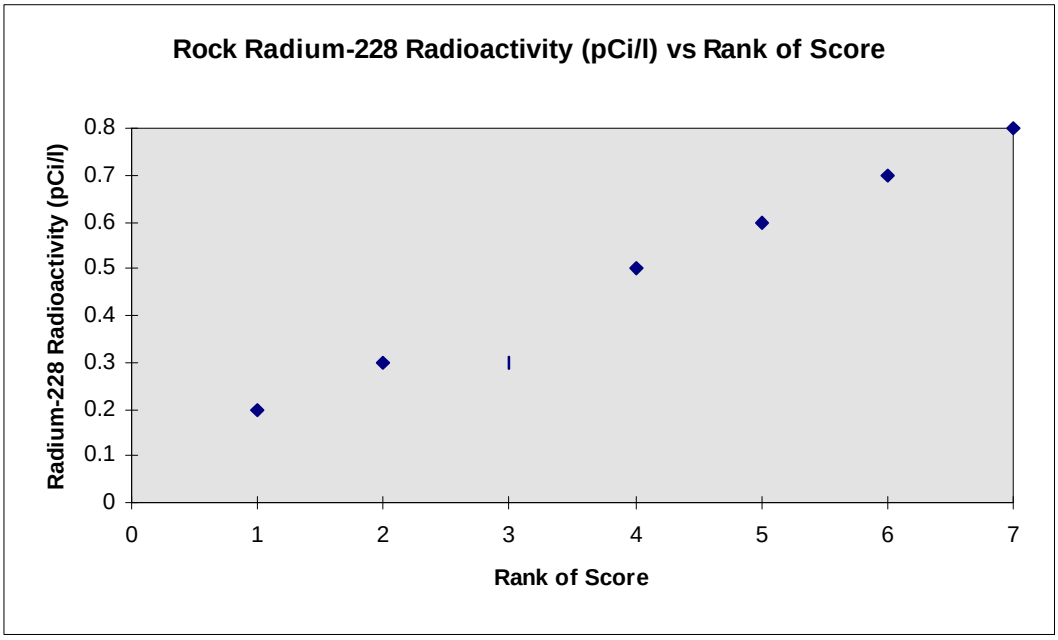


AVERAGE: 0.12 pCi/g
MAXIMUM: 0.20 pCi/g

FIGURE 9: BACKGROUND RADIUM DATA FOR ROCKS



AVERAGE: 0.8 pCi/g
MAXIMUM: 2.4 pCi/g



AVERAGE: 0.5 pCi/g
MAXIMUM: 0.8 pCi/g

V. DISCUSSION OF ENVIRONMENTAL IMPACT

A. Objective

The completion of this study meets the overall objective of investigating NORM contamination at oil and gas wells in New York State. More specifically, the NORM investigation has expanded upon earlier, more limited, investigations in two distinct manners. First, more extensive radiation surveys were conducted. Second, and most importantly, samples were collected to quantify NORM isotopes. By strategically selecting a variety of sample locations and matrices, a broad characterization of oil and gas-related NORM in New York State has been completed. Given the data obtained, a range of NORM concentrations for various categories of media may now be estimated with greater confidence. Consequently, relevant issues such as radiation exposure and waste disposal may be more meaningfully discussed.

B. Radiation Exposure From NORM Concentrations at Oil and Gas Well

Two groups may be exposed to radiation from NORM that is concentrated during oil and gas production: (1) employees of the oil and gas industry and (2) the general public. Many well fields, brine separation areas, brine pits, tanks, and equipment yards were surveyed, at specific locations, with radiation detection instruments. No levels distinguishable from background were detected. This is expected given the low concentrations of NORM measured in the brines, scales, sediments, and sludges. Hence, there is no cause to expect significant radiation exposure to workers or the general public.

C. Disposal of Oil and Gas Well Wastes

Several types of oil and gas well field wastes contain low levels of concentrated NORM. These wastes include gas well brines and well casing scales in addition to oil well sludges and sediments. In this section, the consequence of disposal of these materials is considered.

- *Road Spreading*

The most common method of brine disposal in New York State is via road spreading. Brines are used during winter months as an aid to snow and ice control on roadways. In summer months, brine spreading on rural dirt roads is used for dust control. Theoretically, NORM may concentrate in soils over years of such brine disposal. As noted in the previous section, concentration of NORM has apparently occurred in soils and sediments periodically or continuously saturated with brine.

The BPR concluded that the build-up of NORM on dirt roads, given 20 years of repeated application of the most radioactive brines measured, would not result in public exposures exceeding the NYSDEC TAGM-4003 cleanup guideline of 10 mrem/yr. Theoretically, the most susceptible individuals would be pedestrians who frequently travel such dirt roads. The BPR used the USDOE's Residual Radioactive Material Guideline (RESRAD, version 5.61) dose assessment model to estimate potential doses assuming two hours of road travel per day, 300 days per year. As discussed in detail previously (page 18-19), the model was highly conservative in its approach and, nevertheless, found that resulting exposures posed no threat to the general public or the environment.

Entering mean values for Ra-226 and Ra-228 into the model (0.57 pCi/ml and 1.3 pCi/ml respectively), showed that the resulting dose rate was an order of magnitude lower than the worst-case scenario cited above - less than 0.3 mrem/yr. Entering median values resulted in an even lower dose rate.

Runoff of brine used in snow and ice control on paved roads might have the tendency to concentrate NORM in drainage ditches or swales along the roads. This could result in higher NORM concentrations in the ditches than on dirt roads. However, the exposure scenarios associated with ditches are expected to be considerably less than for pedestrians on roads, and the conclusion stated above remains. Ditches are removed from the direct path of pedestrians. Also, due to the lower elevation of ditch bottoms, the dirt serving as the walls of the ditches shields people traveling the road from direct exposure.

- *Pit Abandonment*

Pit abandonment is one method of sludge and sediment disposal that is *not authorized or considered acceptable by NYSDEC*, but nonetheless occasionally occurs at oil well fields. At such sites, the brines either seep or evaporate away and then leave a discolored sludge and sediment on the bottom of a depression. The brine pits are usually 50-500 square feet in area and one to three feet deep. These sludges or sediments might contain total radium concentrations as high as 12 pCi/g. Use of an abandoned pit would tend to be minimal, particularly without significant clearing, regrading, or other construction work. However, residential development could occur at such an abandoned facility. If it did, the construction work would dilute the total radium concentration, and the foundation and other construction material would provide sufficient shielding such that the dose inside the home would be minimal. In a study of cover and construction material as shielding from a NORM-related dose, Wilson and Scott (1992) were able to cut exposure rates from radium scale (Ra-226) in half with about three inch of soil, three inch of sand, or 1 inch of concrete.

Concerning doses obtained outside the home, such as an amateur gardener might obtain, these doses are also expected to be less than the NYSDEC TAGM-4003 cleanup guideline of 10 mrem/yr. Prior to reuse of an abandoned oil well facility, brine pits would

likely be backfilled. At least two to three inches of topsoil would be required, if not more, to support a grass cover. Assuming a three-inch soil cover on sludge with a total radium concentration of 12 pCi/g and two and one-half hours of outside exposure per day, a dose of less than one mrem/yr is obtained using the Department of Energy's RESRAD modeling software cited earlier. Most of this dose would be from the Ra-226 as the Ra-228 and its progeny would largely be decayed away by the time an abandoned site would be developed.

- *Brine Discharges to Land*

Brines may overflow from separation devices or pits onto the land surface. A few soil samples were collected from such potential overflow areas. While some detectable concentrations of NORM were present, these concentrations were lower than those from brine pit sediments. Given the detected concentrations, the probability of a potentially significant exposure to the public or the environment is extremely unlikely.

D. Recycling of Well Equipment

Due to the low amount of scale present in New York State oil and gas well equipment and due to the low concentration of NORM present in the scales that were found, recycling of oil and gas well equipment should not pose a public health or environmental concern.

E. Conclusions

1. *Several types of oil and gas well field wastes were found to contain slightly concentrated NORM but not at concentrations sufficiently high to pose a threat to the public health or the environment.* These wastes include gas well field brines and well casing scales, and oil well sludges and sediments.

2. *Scale build-up on gas well casings is limited and though one scale sample revealed slightly elevated NORM concentrations, the scale is neither radioactive enough nor present in sufficient quantities to pose an environmental threat.*

3. *Concentrations of NORM in tank bottom scales and sludges and in brine pit sediments were not found to pose a significant threat to the public health or environment.* If construction did occur on a former brine pit, construction activities and filling would likely decrease potential exposure well below the NYSDEC TAGM-4003 cleanup guideline of 10 mrem/yr. Tank bottom sludges would not be present at a high enough concentration and/or in sufficient quantities to generate a hazard to the public health or the environment.

4. Disposal of brines on roads as an aid to snow and ice control does not pose any significant radiological dose to the public due to NORM constituents. This issue was examined extensively using U.S. D.O.E. RESRAD modeling to assess potential doses to the public.

5. *Recycling of oil and gas well equipment should not pose a public health or environmental threat due to the small quantities of scale present and the low concentration of NORM found present in the scale.*

6. *This investigation demonstrates that the concentrations of NORM in oil field wastes in New York State were at least two to three orders of magnitude lower than those found in the North Sea.* The NORM concentrations found in New York State well field wastes do not pose any significant occupational or non-occupational radiological exposure to workers or residents.

APPENDIX A - SITE LOCATION MAPS
APPENDIX B - PHOTOGRAPHS
ARE NOT AVAILABLE IN ELECTRONIC FORMAT

Appendix C - Equipment List

Radiation Survey Instruments:

Ludlum Model 2221 Rate Meter w/Ludlum Model 44-10(2x2) NaI(Tl) probe
S/N meters: 71244/71230
S/N detectors: 114338/114337
Calibration Dates: March 12, 1996 (all)

Eberline Model PRM-5-3 Rate Meter w/Eberline Model SPA-3 (1 inch) NaI(Tl) probe
S/N meter: 2308
S/N detector: 048199
Calibration Date: October 2, 1995

Sampling Devices and Equipment:

Nalgene "Honey-Dipper" Cup with 12 foot extension handle,
Garden Trowels
Stainless Steel 1 inch Coring Device w/T-bar handle and plastic sleeves
Stainless Steel Mixing Bowls
Nalgene 500 cc Sampling Containers (for Lab)
Squeeze Rinse bottles w/plain water and with biodegradable detergent
Rubbing alcohol for equipment rinse
Paper Towels; disposable trash bags

Personal Protective Equipment (PPE):

Steel Toe Boots; Hard hats
Polyethlene gloves (gas wells)
Ruber gloves (oil wells)
Tyvek Coveralls and Booties (Oil Well Sites Only)

Record Keeping Tools:

Paper Pad with Narrative Descriptions and Detailed Field Notes
Chain of Custody Sheets/Sample Logs

Typical Equipment List

Radiation Survey Instruments:

Ludlum Model 2221 Rate Meter w/Ludlum Model 44-10(2x2) NaI(Tl) probe
S/N meters: 71244/71230
S/N detectors: 114338/114337
Calibration Dates: March 12, 1996 (all)

Eberline Model PRM-5-3 Rate Meter w/Eberline Model SPA-3 (1 inch) NaI(Tl) probe
S/N meter: 2308

APPENDIX D TABLE D-1. SAMPLE LIST AND SITE SURVEY RESULTS

Part 1. Survey Results per 2x2 Sodium Iodide (NaI) Detector Probe

Sample # (OG...)	Name of "Site"	Well Type	Sample Type	Description of Sample or Survey Location	Area Survey Readings (cpm)[1]
071201	Parteko N-748	gas	water	top of blow-down hole	~ 10,000
NA	Finen N-785	gas	-	* No Sample Collected	-
NA	Morris 1	gas	-	* No Sample Collected	-
NA	Dutch Hill	oil	-	* No Sample Collected	~8,000
NA	Dutch Hill	oil	-	base of metal stock tanks	~5,000
071801	Fuchs 1	gas	brine	brine tank	10,000
071802	Fuchs 1	gas	soil	beneath spigot on brine tank	13,000
071803	near Fuchs 1	gas	soil	background soil, about 100' from well	-
071804	Skinner	gas	brine	brine tank	-
071805	Rachic 1	gas	soil	soil composite, stained area near base of tank	17,000
071806	Rachic 1	gas	brine	brine tank	10,000 - 13,000
071901	Kelview	gas	brine	brine tank (rusted)	-
071902	Benz	gas	water	open brine tank	-
071903	Schictel	gas	brine	brine tank	-
071904	Mahl	gas	brine	brine tank	-
080701	Snyder 6	gas	brine	bottom of brine tank	8,000
080702	Oles 1	gas	brine	bottom of brine tank	9,000
080703	Bruning 1	gas	brine	brine tank, subsurface	-
080704	Halek	gas	brine	brine tank	< 8,000
080705	Dickens 3	gas	brine	brine tank	5,000

APPENDIX D TABLE D-1. SAMPLE LIST AND SITE SURVEY RESULTS

Sample # (OG...)	Name of "Site"	Well Type	Sample Type	Description of Sample or Survey Location	Area Survey Readings (cpm)[1]
080706	Dickens 2	gas	brine	brine tank, subsurface	6,500
080707	Miller 1	gas	brine	brine tank, subsurface	10,000
080708	Miller 1	gas	rock	shale/soil at ground surface	10,000
080709	U.S. Gypsum Equipment Yard	(gas)	scale	scale, rust, soil, grout from inside of a 4" casing	-
080710	U.S. Gypsum Equipment Yard	(gas)	scale	scale and rust from inside ends of 1-1/2" stringers	-
080711	U.S. Gypsum Equipment Yard	(gas)	scale	rust and scale from bottom of gas well separator tank	-
* No Sample	U.S. Gypsum Equipment Yard	(gas)	-	Front of garage bays; area of "sweepings"	-
080712	A.K. Koers 1	gas	brine	brine tank	-
080713	Titus 3	gas	brine	brine tank (rusted)	10,500
080714	Titus 1	gas	brine	brine tank	9,500
080715	D Chamberlain 2	gas	brine	brine tank	-
080716	R Chamberlain	gas	brine	brine tank	11,500
080717	Tozier 1	gas	brine	brine tank	12,000
080801	Cal Ban, CB45	oil	soil	"background" soil, about 120' from oil separator	~15,000
080802	Cal Ban, CB45	oil	soil	soil, composite from brine run-off ditch	~15,000
080803	Cal Ban, CB45	oil	crude oil	product from top of separator tank	~15,000
080804	Cal Ban, CB45	oil	sludge	"gunk" from bottom of separator tank	~15,000

APPENDIX D TABLE D-1. SAMPLE LIST AND SITE SURVEY RESULTS

Sample # (OG...)	Name of "Site"	Well Type	Sample Type	Description of Sample or Survey Location	Area Survey Readings (cpm)[1]
080805	Cal Ban separator near well CB 8,	oil	soil	"background" soil, about 70' from separator unit	~13,000
080806	CalBan separator near well CB 8	oil	sediment	soil, composite from brine run-off ditch	~13,000
080807	Cal Ban separator near well CB 8	oil	sediment	sediment cores (3) from bottom of brine pond	~13,000
* No Sample	Kinley wells, Knapp Creek	oil	-	area around rig pulling water injection tubes	~10,000
080808	Kinley Oil Co., pulled pipe	oil	wax	rusty "gel" or paraffin from ends of 2" pipes (12)	9,500
080809	BDH Wellfield, Nichol's Run Rd	oil	soil	"background" soil, 20' uphill from separator unit	~14,000
080810	BDH Wellfield, Nichol's Run Rd	oil	sediment	composite of bottoms in old brine pit	~14,000
080811	BDH Wellfield, Nichol's Run Rd	oil	sediment	composite of soils from oily surface run-off swale	~14,000
080812	BDH Wellfield, Nichol's Run Rd	oil	sludge	Gunk from cleanout ports at base of product tanks (5)	~14,000
080813	BDH Wellfield, Nichol's Run Rd	oil	sludge	bottom of separator sludge tank	~14,000
080814	BDH Wellfield, Nichol's Run Rd	oil	wax	oil, dirt, sludge, wax from old separator tank	~14,000
080815	BDH Wellfield, Nichol's Run Rd	oil	sludge	bottom sediment from primary separator tank	~14,000
* No Sample	Avoca Gas Storage Project	disp	-	rock cores from various depths to 10,000'	5,000 - 7,500
080901	Avoca, Deep Well #3	disp	rock	sandy cuttings by washer pond (~11,000' depth)	-

APPENDIX D TABLE D-1. SAMPLE LIST AND SITE SURVEY RESULTS

Sample # (OG...)	Name of "Site"	Well Type	Sample Type	Description of Sample or Survey Location	Area Survey Readings (cpm)[1]
080902	Avoca, Deep Well #3	disp	rock	rock chips by washer pond (~11,000')	-
080903	Avoca, Deep Well #6	disp	rock	residual cuttings by washer pond (unknown depth)	-
080904	Avoca Gas Storage Project	brine	rock	cuttings in wash pile (~3,000'	-
080905	Avoca Gas Storage Project	brine	rock	cuttings in wash pile (~3,000)	-
102901	Murty 1	gas	brine	bottom of brine tank	10,000
102902	Crossman 1	gas	brine	bottom of brine tank	11,000
102903	NY Oil & Gas Equipment Drop	gas	scale	pipes and valves	8,000
102904	Persons 1	gas	brine	brine tank	-
102905	Button 1	oil	brine	brine tank	8,000
102906	Cowles 3	gas	brine	brine tank	-
102907	Barger 1	oil	brine	brine tank	-
102908	Morton 1	oil	oil	spigot at base of stock tank	8,000-9,000
102909	Morton 1	oil	brine	brine drain tank	8,000-9,000
102910	Resource America Equipment Yard	gas	sludge	A composite of sludge from three gas separator units	8,000-9,000
102911	Resource America Equipment Yard	gas/ oil	scale	Exterior scale from outer gas well casings	8,000-9,000
102912	Resource America Equipment Yard	gas/ oil	scale	Scale and rust from inside of 2½" casings in yard	8,000-9,000

APPENDIX D TABLE D-1. SAMPLE LIST AND SITE SURVEY RESULTS

Sample # (OG...)	Name of "Site"	Well Type	Sample Type	Description of Sample or Survey Location	Area Survey Readings (cpm)[1]
102913	Resource America Equipment Yard	gas/ oil	scale	Scale and rust from inside stringers	8,000-9,000
102914	Resource America Equipment Yard	oil	scale	Scale inside 4" casings	8,000-9,000
102915	Resource America Equipment Yard	oil	wax	Paraffin from plunger rods	8,000-9,000
NA	Niefergold-Arnold 1	gas	-	* No Sample Collected	10,000 - 11,000
103001	Broadway-Paxson 1148	gas	brine	brine tank	9,000-10,000
103002	C. Paggett	gas	brine	brine tank	8,000-10,000
103003	Hill 6	gas	brine	brine tank	8,000-9,000
103004	NYRA 13, 18	gas/ oil	brine	bottom of stock tank	11,000-12,000
103005	Tompsett 4	oil	brine	from bottom drain tank	10,000-13,000
103006	Tompsett 4 (some equipment there)	gas	sludge	sludge from bottom of a gas well separator unit	10,000-13,000
103007	Gross 6	oil	wax	from barrel near swabbed pipes	-
103008	OGLS Equipment Yard	oil	wax	from ends of surplus pipes	-
103009	Lipari 1, et al	oil	sludge	from bottom of sludge collection tank	-
103010	Darling 339	oil /gas	brine	brine tank	-

APPENDIX D TABLE D-1. SAMPLE LIST AND SITE SURVEY RESULTS

Sample # (OG...)	Name of "Site"	Well Type	Sample Type	Description of Sample or Survey Location	Area Survey Readings (cpm)[1]
103011	Brininger-Nelson 233	gas	brine	brine tank	9,000-10,500
103012	MacNallie 162	gas	brine	brine tank	~9,000
103013	Hoover	gas	brine	brine tank	8,000-10,000
103101	Empire Exploration 1706	gas	brine	brine tank	~12,000
103102	BDH Oil	oil	water	stream discharge	~12,000
103103	BDH Oil	oil	sediment	trowel of sediment beneath stream discharge	~12,000
103104	BDH Oil Separator	oil	sediment	composite from first brine pond	12,000-13,000
103105	BDH Oil Separator	oil	sludge	bottom sediment from separator tank	12,000-13,000
110101	Hoyt #8	oil	sediment	composite from brine pond	~9,000
110102	Hoyt #8	oil	brine	separator tank	~9,000
110103	Allen 1-3	oil	sediment	composite from brine drip	-
110104	Allen 1-3	oil	wax	from off-line separator drum	-
110105	Cunningham 490	gas	brine	brine tank	11,000 -12,000
110106	Van Campen 2315	gas	brine	brine tank	-
120501	Barnhart	gas	brine	brine tank	~12,000
120502	Lacher	gas	brine	brine tank	~13,000

APPENDIX D TABLE D-1. SAMPLE LIST AND SITE SURVEY RESULTS

Part 2. Survey Results per 1" Sodium Iodide (NaI) Detector Probe.[2]

Sample# (OG...)	Name of "Site"	Well Type	Sample Type	Description of Sample or Survey Location	Area Survey Readings (cpm)[1]
* No Sample	Owens-Illinois Office/Yard	gas	-	collector/separator apparatus	~400-475
* No Sample	Donovan Road	gas	-	drip at pipeline crossing	< 500
* No Sample	Fosterville Road	gas	-	drip at pipeline crossing	< 500
100701	Gould 1033	gas	brine	spigot at base of brine tank	400-500
100702	Gould 1046	gas	brine/rust	spigot at base of brine tank	400-500
100703	Gould 1046	gas	brine	spigot at base of brine tank	400-500
100704	D.J.Farms 1158	gas	brine	spigot at base of brine tank	~250-400
100705	Robson 1201	gas	brine	spigot at base of brine tank	~250-400
100706	Ritter 1019	gas	brine	spigot at base of brine tank	~500
100707	Meridian	gas	scale	open brine tank	-
100708	Owens-Illinois	gas	salt scale	salt crystal from gas collector system	-
100709	Owens-Illinois	gas	rock	piece of Queenston core	-
100901	Thater 53	gas	brine	from brine tank	-
100902	Sinclair 91	gas	brine	from brine tank	-
100903	Ashley 7265	gas	brine	from brine tank	-
100904	Meridian Yard	gas	scale/rust	end of separator	300-500

1 - A dash in the last column of the table indicates site locations where no readings were taken with a field radiation survey instrument.

2 - The original plan for field work during this project was to use a 2"x 2" NaI probe. However, due to competing priorities during the period of Trip 4, a 1 inch NaI detector had to be used.

TABLE E-1. FIELDS AND FORMATIONS SAMPLED AND/OR SURVEYED				
FIELD	**COUNTY**	**FORMATION**	**TYPE OR PRODUCTION**	**OG SAMPLE #S**
Lakeshore	Chautauqua	Medina	Gas	102901-04, 06, 10-13; 103003, 12, 13
Lakeshore	Cattaraugus	Medina	Gas	103002
Ashford	Cattaraugus	Medina	Gas	071801-017806; 071901, 03, 04
Sardinia	Erie	Medina	Gas	071902
North Collins	Erie	Medina	Gas	103001
Concord	Erie	Medina	Gas	103101
Alden-Lancaster	Erie	Medina	Gas	080701
Alden-Lancaster	Genesee	Medina	Gas	080702
Indian Falls	Genesee	Medina	Gas	080703-080706
Huron Creek	Genesee	Medina	Gas	080707-080711
Alexander	Genesee	Medina	Gas	080712
Uhley Corners-Caledonia	Genesee	Medina	Gas	100901
Uhley Corners-Caldeonia	Livingston	Medina	Gas	100902
Whetstone Brook	Ontario	Medina	Gas	100903
Fayette-Waterloo	Seneca	Queenston	Gas	100704-100705, 07
West Auburn	Cayuga	Queenston	Gas, low flow	100708-100709
West Auburn	Cayuga	Queenston	Gas	100701-100703; 100904
Reeder Creek	Seneca	Rochester Shale	Gas	100706
Tozier's Corners	Wyoming	Akron	Gas	080717
Wyoming/Cascade	Wyoming	Theresa (Rose Run)	Gas	080713-080716
State Line	Allegany	Oriskany	Gas	110105, 06
Lebanon	Madison	Herkimer-Oneida	Gas, Fractured	071201
Stagecoach	Tioga	Helderberg	Gas, Pressure	120501, 02
Ellery	Chautauqua	Bass Island	Gas	103011
Ellery	Chautauqua	Bass Island	Gas-Oil	103010
Harmony	Chautauqua	Bass Island	Oil	102905

TABLE E-1. FIELDS AND FORMATIONS SAMPLED AND/OR SURVEYED				
FIELD	**COUNTY**	**FORMATION**	**TYPE OR PRODUCTION**	**OG SAMPLE #S**
North Harmony	Chautauqua	Bass Island	Oil	102907-09, 14-15
Gerry-Charlotte	Chautauqua	Bass Island	Oil	103005-103009
Unnamed	Chautauqua	Bass Island?	Gas, Oil, New	103004
Bradford	Cattaraugus	Bradford/Bradford Third	Oil, Primary?	080808
Bradford	Cattaraugus	Bradford	Oil, Primary	103102, 03
Bradford	Cattaraugus	Bradford/Chipmunk	Oil, Secondary	103104, 05
Bradford	Cattaraugus	Chipmunk	Oil, Secondary	080809-080815
Five Mile	Cattaraugus	Bradford/Chipmunk	Oil, Primary	080801-080804
Five Mile	Cattaraugus	Bradford	Oil, Primary	080805-080807
Richburg	Allegany	Richburg	Oil, Primary	110101-110104
Dutch Hill	Cattaraugus	Onondaga	Oil, Primary	No Sample Collected
Avoca	Steuben	Pre-Cambrian	Deep Disposal	080901-080903
Avoca	Steuben	Salina-Vernon	Brine Solutioning	080904, 05

NOTE: All wells surveyed and sampled were active status except the oil wells associated with sample OG080808 (Bradford Third Formation). These were recently plugged and abandoned or having pipe pulled. Three of the Theresa gas wells sampled appeared inactive upon field inspection, one apparently having been shut-in for some time; however, all of these had valid operating permits.

TABLE E-2. SPECIFIC WELL INFORMATION

Sample ID#(s)	Well Name(s) (or Lease)	Well Type	API Well#(s)	County	Geologic Formation	Surface Elevation (MSL)	Dept of Well (feet)	Date of Well Completion
071201	Parteko N-748	Gas	053-04002	Madison	Herkimer-Oneida	1694	2794	May 1960
071801, 071802, 071803	Fuchs 1	Gas	009-20899	Cattaraugus	Medina	1910	4104	April 1988
071804	Skinner 1	Gas	009-21775	Cattaraugus	Medina	1900	3500	Sept. 1989
071805, 071806	Rachic 1	Gas	009-20787	Cattaraugus	Medina	1790	3878	March 1987
071901	Kelview 1	Gas	009-11723	Cattaraugus	Medina	1370	3304	March 1976
071902	Benz 1	Gas	029-15761	Erie	Medina	1330	3178	Feb. 1981
071903	Schichtel 1	Gas	009-12475	Cattaraugus	Medina	1342	3310	June 1977
071904	Mahl 1	Gas	009-20228	Cattaraugus	Medina	1350	3350	Jan 1986
080701	Snyder 6	Gas	029-19097	Erie	Medina	880	1323	July 1984
080702	Oles 1	Gas	037-21549	Genesee	Medina	877	1340	Oct. 1994
080703	Bruning 1	Gas	037-20530	Genesee	Medina	757	864	Sept 1987
080704	Halik 1	Gas	037-21311	Genesee	Medina	837	990	July 1990
080705	Dickens 2	Gas	037-19425	Genesee	Medina	818	925	July 1985
080706	Dickens 3	Gas	037-20600	Genesee	Medina	803	904	Oct. 1989
080707, 080708	Miller 1	Gas	037-13300	Genesee	Medina	910	1273	June 1978
080709 ,080710, 080711	Miscellaneous	Gas	NA	Erie, Genesee, Wyoming	Medina	--	--	--
080712	Koers 1	Gas	037-21337	Genessee	Medina	1140	1752	Nov 1990

TABLE E-2. SPECIFIC WELL INFORMATION

Sample ID#(s)	Well Name(s) (or Lease)	Well Type	API Well#(s)	County	Geologic Formation	Surface Elevation (MSL)	Dept of Well (feet)	Date of Well Completion
080713	Titus 3	Gas	121-22046	Wyoming	Theresa	1040	4929	July 1991
080714	Titus 1	Gas	121-21920	Wyoming	Theresa	1200	5183	Dec 1990
080715	D Chamberlain 2	Gas	121-21907	Wyoming	Medina	1420	2447	Feb 1991
080716	R. Chamberlain	Gas	121-21946	Wyoming	Theresa	1180	5140	Dec 1990
080717	Tozier 1	Gas	121-16017	Wyoming	Akron	1350	2080	Dec 1994
080801, 080802, 080803, 080804	Thropp CBB1, CBB2, CBB3	Oil	009-21880, 009-22036, 009-21925	Cattaraugus	Bradford	1850	870	1990, 1991
080805, 080806, 080807	CB 8, CB10, CB19, CB20, CB21, CB51, CB52, CB53	Oil	009-18616, 009-18561, 009-19793, 009-19772, 009-18741, 009-17779, 009-17780, 009-17781	Cattaragus	Bradford	1650	1300-1600	1982, 1983, 1984
080808	Unknown	Oil	Unknown	Cattaraugus	Bradford	?	?	?
080809, 080810, 080811, 080812, 080813, 080814, 080815	Nichols Run AW1, AW4, AW5, AO1, AO3	Oil	009-64946, 009-64949, 009-64950, 009-64942, 009-64944	Cattaraugus	Chipmunk	?	1200-1600	1953, 1954
080901, 080902	Mitchell 3	Disp	101-21633	Steuben	Pre-Cambrian	1680	11415	July 1996
080903	Fee 6	Disp	101-21636	Steuben	Pre-Cambrian	1700	11030	June 1996
080904, 080905	Fee 6	Disp	101-21627	Steuben	Vernon	1744	3798	June 1996
100701	Fee 3A	Salt	011-20615	Cayuga	Queenston	588	1975	Nov 1988
100702, 100703	Gould 1033	Gas	011-20616	Cayuga	Queenston	575	1978	Nov 1988
100704	Gould 1046	Gas	099-21293	Seneca	Queenston	601	2122	Feb 1990

TABLE E-2. SPECIFIC WELL INFORMATION

Sample ID#(s)	Well Name(s) (or Lease)	Well Type	API Well#(s)	County	Geologic Formation	Surface Elevation (MSL)	Dept of Well (feet)	Date of Well Completion
100705	D.M. Farms 1158	Gas	099-21323	Seneca	Queenston	582	2125	May 1990
100706	Robson 1201	Gas	099-21251	Seneca	Rochester Shale	584	1554	June 1989
100707	Ritter 1019	Gas	Unknown	Seneca		?	?	?
100708	Unknown	Gas	NA	Cayuga		--	--	--
100709	Unknown	Gas	Unknown	Cayuga	Queenston	?	?	?
100901	Thater 53	Gas	037-14526	Genesee	Medina	943	1648	June 1981
100902	Sinclair 91	Gas	051-17316	Livingston	Medina	895	1666	June 1982
100903	Ashley 7265	Gas	069-21501	Ontario	Medina	833	2375	Nov 1993
100904	Miscelleneious	Gas	NA	Cayuga	Queenston	--	--	--
102901	Murty 1	Gas	013-21817	Chautauqua	Medina	628	2311	Dec 1989
102902	Crossman 1	Gas	013-16325	Chautauqua	Medina	690	2557	Aug 1981
102903	Miscellaneous	Gas	NA	Chautauqua	Medina	--	--	--
102904	Persons 1	Gas	013-17796	Chautauqua	Medina	1580	3857	Aug 1982
102905	Button 1	Oil	013-21156	Chautauqua	Bass Island	1815	2999	Sept 1988
102906	Cowles 3	Gas	013-12127	Chautauqua	Medina	1385	4025	Oct 1977
102907	Barger 1	Oil	013-18343	Chautauqua	Bass Island	1651	3107	July 1983
102908, 102909	Morton 1B	Oil	013-19243	Chautauqua	Bass Island	1372	2865	Oct 1984
102910, 102913	Miscelleneous	Gas	NA	Chautauqua	Medina	--	--	--

TABLE E-2. SPECIFIC WELL INFORMATION

Sample ID#(s)	Well Name(s) (or Lease)	Well Type	API Well#(s)	County	Geologic Formation	Surface Elevation (MSL)	Dept of Well (feet)	Date of Well Completion
102911, 102912, 102914	Miscellaneous	Gas-Oil	NA	Chautauqua	Medina, Bass Island	--	--	--
102915	Miscellaneous	Oil	NA	Chautauqua	Bass Island	--	--	--
103001	Broadway-Paxson 1148	Gas	029-09050	Erie	Akron	?	?	?
103002	C Paggett	Gas	009-17220	Chautauqua	Medina	1300	3240	Sept 1983
103003	Hill 6	Gas	013-18286	Chautauqua	Medina	2024	4142	June 1983
103004	NYRA 13, 18	Gas-Oil	013-22582, 013-22590	Chautauqua	Medina, Perrysburg	1980	4000, 1293	Pending
103005	Tompsett 4	Oil	013-19733	Chautauqua	Bass Island	1735	2988	Dec 1984
103006	Miscellaneous	Gas	NA	Chautauqua	Medina	----	----	-----
103007	Gross 6	Oil	013-19905	Chautauqua	Bass Island	1305	2466	June 1995
103008	Miscellaneous	Oil	NA	Chautauga	Bass Island	----	----	----
103009	Lipari 1	Oil	013-16819	Chautauqua	Bass Island	1333	2474	Feb 1982
103010	Darling 339	Gas-0il	013-20208	Chautauqua	Bass Island	1605	3070	Aug 1990
103011	Brininger-Nelson	Gas	013-18767	Chautauqua	Medina	1640	3946	Feb 1984
103012	MacNallie 162	Gas	013-18024	Chautauqua	Medina	?	4203	1982
103013	Hoover	Gas	013-21857	Chautauqua	Medina	1504	4391	June 1990

TABLE E-2. SPECIFIC WELL INFORMATION

Sample ID#(s)	Well Name(s) (or Lease)	Well Type	API Well#(s)	County	Geologic Formation	Surface Elevation (MSL)	Dept of Well (feet)	Date of Well Completion
103102, 103103	Nichols Run HO-28, HW-18, HW-22, HW-34	Oil	009-65540 009-65354 009-65358 009-65369	Cattaraugus	Bradford, Chipmunk	?	1100	1965, 1966
103104, 103105	Nichols Run GO-18, GW-21, GW-22 HA, HO-21, HW-21	Oil	009-65098 009-65127 009-65128 009-06391 009-65533 009-65357	Cattaraugus	Bradford, Chipmunk	1900	1150	1962, 1965
103101	Empire Exp 1706	Gas	UNK	Erie	Medina	?	?	?
110101, 110102	Hoyt 8	Oil	003-15562	Allegany	Richburg	?	847	Oct 1980
110103, 110104	Allen 1, Allen 2, Allen 3	Oil	003-67673, 003-67674, 003-67675	Allegany	RIchburg	?	?	?
110105	Cunningham 490	Gas	003-20116	Allegany	Oriskany	2066	4923	Oct 1995
110106	VanCampen 2315	Gas	003-66428	Allegany	Oriskany	?	4771	Jan 1935
120501	Barnhart	Gas	107-20644	Tioga	Helderberg	1480	5127	Nov 1988
120502	Lacher	Gas	107-21394	Tioga	Helderberg	1475	5283	Dec 1990

Appendix F - Instrument Quality Assurance Procedures

Instruments Used

Quality of results is based in large part on the quality of the instruments used. To this end the Bureau of Pesticides & Radiation endeavors to maintain properly functioning instrumentation. Annual calibrations, routine maintenance and performance checks, and pre-field/post-field source checks all serve to document instrument accuracy and precision.

This investigation of NORM at oil and gas wells relied, for the most part, upon a 2x2 NaI(Tl) detector with an electronic rate meter. This instrument was chosen because of its enhanced sensitivity (over a sta probe) to the low energy gamma rays associated with NORM constituents. The two such instruments used durin six field trips were:

Ludlum Model 2221 rate meter SN 71230 with a Ludlum Model 44-10 (2x2) NaI(Tl) detector probe SN 114337; Calibration Date March 12, 1996

Ludlum Model 2221 rate meter SN 71244 with a Ludlum Model 44-10 (2x2) NaI(Tl) detector probe SN 114338; Calibration Date March 12, 1996

Because of competing priorities during the period of Trip 4, a 2x2 NaI(Tl) detector probe was not available. For that trip, a less-sensitive 1inch NaI(Tl) probe (still preferable to the G-M) was used:

Eberline Model PRM-5-3 rate meter SN 2308 with a Eberline Model SPA-3 (1 inch) NaI(Tl) detector probe SN 048199; Calibration Date October 2, 1995

Instrument Check-Out Procedure

Prior to field work, quality assurance (QA) checks were performed per Bureau procedures on the survey instrument to be used. The battery level and high voltage (HV) settings were checked. Office background checks were performed and a check source procedure followed. The check source procedure involved measurement of a 1 μCi Cs-137 check source. The instrument should operate within acceptable ranges determined, under Bureau procedures, after each instrument's annual calibration. Records of these checks are kept with notations of any problems.

Field QA Checks

Field QA checks included periodic checks of the battery and high voltage settings. Background readings were performed as well. Readings were typically about 5,000 cpm inside the vehicle and outdoor readings typically 7,000 to 14,000 cpm, depending upon the natural setting. The instruments were kept indoors at night and were covered with plastic bags during inclement weather. The instruments operated properly throughout the duration of this investigation.

Instrument Check-In Procedure

Upon return to the NYSDEC office all field instruments must be checked in, per Bureau procedures, using the office check source. Battery and high voltage checks are performed as well, and all results are recorded.

The acceptable range and readings for the 1μCi Cs-137 office control check source for each excursion, are listed in **Table F-1** below. While several of the readings are not within the acceptable range for the office check source, the results are considered valid for the purpose of the survey. The survey contrasted relative readings between background and the area of the site in question. Exact quantitative measurement was not considered necessary as long as NORM could be adequately detected and contrasted with background. The values determined for background for the field excursions are listed in **Table F-2**.

Table F-1. Field Instrument Source Check Readings

1996 Field Trips	Acceptable Range for Office Check Source (cpm)	Pre-Inspection Reading (cpm)	Post-Inspection Reading (cpm)
Ludlum Model 2221 Rate Meter with a Ludlum Model 44-10 2x2 NaI(Tl) Detector Probe (Meter SN 71230/Probe SN 114337)			
Trip 1 (7/12)	126,683 - 129,789	126,356	125,478
Ludlum Model 2221 Rate Meter with a Ludlum Model 44-10 2x2 NaI(Tl) Detector Probe (Meter SN 71244/Probe SN 114338)			
Trip 2 (7/18-7/19)	118,758 - 121,253	119,308	119,427
Trip 3 (8/7 - 8/9)	118,758 - 121,253	121,230	118,166
Trip 5 (10/29-11/1)	121,032 - 123,618	119,096	118,557
Trip 6 (12/5-12/6)	121,032 - 123,618	117,388	117,571
Eberline Model PRM-5-3 Rate Meter with a Eberline Model SPA-3 (1 inch) NaI(Tl) Detector Probe (Meter SN 2308/Probe SN 048199)			
Trip 4 (10/7-10/9)	35,252 - 43,248	37,000	37,000

Table F-2. Background Readings for Field Radiation Surveys

1996 Field Trip	Background (cpm)		
	Office	Vehicle	Field, Open-Air
Ludlum Model 2221 Rate Meter with a Ludlum Model 44-10 2x2 NaI(Tl) Detector Probe			
Trip 1 (7/12)	~ 8,000	Not Recorded	~ 10,000
Trip 2 (7/18-7/19)	~ 7,000	~ 5,000	8,000 - 10,000
Trip 3 (8/7 - 8/9)	~ 6,800	~ 5,000	5,000 - 15,000
Trip 5 (10/29-11/1)	~ 7,400	~ 4,500	8,000 - 12,000
Trip 6 (12/5 - 12/6)	~ 7,400	Not Recorded	~ 12,500
Eberline Model PRM-5-3 Rate Meter with a Eberline Model SPA-3 (1 inch) NaI(Tl) Detector Probe			
Trip 4 (10/7 -10/9)	~ 350	100 - 120	250 - 500

Appendix G - Introduction to Table G-1

Background on the Spectroscopy Used to Build Table G-1

The focus of the spectroscopy work was to determine the concentrations of radium-226 and radium-228 on equipment used and in wastes generated during oil and gas production in New York State. These two isotopes are produced by the radioactive decay of uranium and thorium, respectively. While uranium and thorium produce a series of radioactive isotopes in the soil sub-surface, referred to as their decay chains (see **Figures G-1/G-2,** pages G-4 and G-5), radium is selectively brought to the surface by oil and gas production due to its greater relative solubility over other isotopes. Subsequently, radium isotopes are deposited on the interior of pipes, tubing, and oil or gas production equipment, as well as in waste materials such as brines and sludges. Radium isotope decay progeny may also be a source of radiation but decay away quickly with the exception of the radium-224 progeny, Pb 210. Resulting NORM contamination can range from the benign to concentrations similar to that of uranium mill tailings (Eisenbud, 1987).

To search for these naturally occurring radioactive isotopes, both gamma and alpha spectroscopy was used. Gamma spectroscopy compares emitted gamma wavelengths (high energy X-rays) of a radioactive material with known emission spectra of various radioactive elements. A similar procedure, alpha spectroscopy, can be used to identify alpha emitters. Some elements are more readily identified than others due to less overlap of their emission spectra. For instance, radium-226 is difficult to distinguish from uranium-235, an isotope commonly occurring in soils. As neither of the radium isotopes are readily identified by gamma spectroscopy, daughter products of these isotopes were quantified. For example, lead-214 and bismuth-214 were measured in order to estimate the amount of radium-226 present.

Use of Spectroscopy to Estimate Radium Concentrations

To understand the spectroscopy results, a comprehension of the production and measurement limitations of radium-226 and radium-228 is required. Both radium-226 and -228 are naturally occurring radioactive isotopes, the products of the uranium and thorium decay chain respectively. Though these two chains can be assumed to be in equilibrium during subsurface conditions , the radium (Ra-226 for the uranium chain and Ra-228 and Ra-224 for the thorium chain) is disproportionately removed during oil and gas extraction due to radium's greater solubility. Thus, the parent isotopes of radium (U-238, Th-234, Pa-234, U-234, Th-230 for the uranium chain; Th-232 for the thorium chain) tend to be relatively scarce. This is apparent from **Table G-1** - samples #071806 and #100703 being particularly good examples.

Despite the parent isotopes' disequilibrium with radium levels, from radium-224/226 to the end of the uranium and thorium chains, respectively, a quasi-equilibrium exists. A true equilibrium does not exist in both chains as the immediate daughter product of Ra-226 and Ra-224 is radon gas. This gas tends to diffuse out of the sampled material (22% is lost from sludges; 5% is lost from scales; and an unknown amount is lost from brines), and thus radon and its progeny are reduced relative to the radium concentrations in the materials. To allow an equilibrium between radium and its progeny to be reestablished, the samples were sealed and held for a minimum of two weeks prior to measurement.

However, holding the samples for two weeks does not permit sufficient regeneration of radium-224 from its parent isotope, thorium-228, for complete equilibrium to be established in the thorium chain. The radium-224 has a short-half (3.6 days) and quickly becomes depleted due to the long half life of thorium-228 (1.9 years). Not enough radium-224 is regenerated initially to replace that being lost. This disequilibrium will continue until sufficient thorium-228 can build up to permit regeneration of more radium-224. Such a process will take much longer than two weeks. However, by measuring the radioactivity of actinium, above thorium-228 in the chain, one can obtain an accurate assessment of the radium-228 quantities. One is not likely to obtain an accurate assessment of radium-228 concentrations via analysis of progeny lower on the chain, i.e. Pb-212 and Tl-208.

Hence, the thorium chain is somewhat more problematic to evaluate. To accurately assess radium-228 concentrations, the best approach is to use its immediate daughter, actinium-228, as an indicator and measure its activity. Though lead-212 and thallium-208 are just as readily quantified by gamma spectroscopy, as described above, disequilibrium considerations make lead and thallium poor indicators of radium-228 concentrations. On the other hand, lead-214 and bismuth-214 are the best available indicators for radium-226.

In short, the best estimate of radium-228 concentrations is the actinium-228 result. However, the higher of the lead-212/ thallium-208 result was used in the rare instance that one of the latter exceeded the actinium value (in the vast majority of cases the actinium value was the highest, as expected). The most accurate estimate of radium-226 concentrations is either the lead-214 or the bismuth-214 spectroscopy result. As a conservative approach, the higher of each was recorded as the estimate. The radium-226 result was recorded on the table but was not used in formulating an estimate due to uranium-235 interference.

Comparison of BPR/TNT Results

Nine samples were analyzed by both the NYSDEC BPR and the TNT contract lab. While both sets of results indicated low concentrations of NORM and appeared internally consistent based on each lab's duplicate sampling, there was limited agreement between labs on point estimates and their respective error ranges. For Ra-226 and Ra-228 estimates (the most critical of the NORM isotopes under consideration), the stated error ranges for a given estimate did not overlap from one lab to the other in 10 out of 18 cases. Of these, seven were not within a near proximity of overlap (within 50% of the larger estimate). Five sets of values differed by a factor of two, while four sets of values differed by a factor of three. The most significant disagreement occurred for a brine sample: a ten-fold difference between labs for the reported Ra-226 concentrations (the BPR result being higher). When there was a significant difference, BPR radium results were higher than the TNT results six out of the 10 times.

A partial explanation for these discrepancies may consist of the following differences in approach to gamma spectroscopy: (1) the BPR laboratory performed geometry and self-absorption corrections on all final values, while TNT did not; (2) the BPR laboratory was capable of better resolution of isotopes - detection of two channels per keV versus TNT's one channel per keV; (3) the BPR laboratory used manual analysis to a greater extent, thus permitting greater discretion in the interpretation of spectral results; (4) the BPR laboratory used a shorter measuring time (30 - 60 minutes)

than the TNT laboratory (8 hours), with a longer measuring time correlating with more accurate results; (5) the BPR laboratory used a "tub" rather than a Marinelli beaker as a sample holder during measurements - the former being less prone to error; and (6) there may have been differences in the allotted time for samples to reach a radioactive decay equilibrium. The BPR allowed the samples to rest in a sealed container for two weeks prior to measurement, while TNT may not have allowed the samples to rest for quite as long.

Uniform standards measured by both laboratories would have been an excellent means of comparing the two laboratories results. Unfortunately, time constraints did not permit the use of uniform standards

.

Despite the differences in results between the two labs for certain duplicated efforts, it should be emphasized that *both labs indicated relatively low concentrations of NORM*.

Key to Table G-1

OG ID#: A six digit number used to identify the source of the sample. If followed by a "D", it indicates that this is the second of two samples taken from a single source.

TYPE: Indicates whether the sampled source was a brine (salty solution produced as a byproduct of oil/gas abstraction), oil, scale (mineral deposit on interior of pipes/tubing), soil, sediment, wax (paraffin deposit on interior of pipes/tubing), sludge (deposited in production equipment) or water (distinguished from a brine as not a byproduct of oil/gas abstraction).

γD,γT,αT: The second part of each cell indicates the type of analysis performed. γD for gamma spectroscopy performed by the DEC itself; γT for gamma spectroscopy performed by Thermo NUtech (TNT), a laboratory employed under contract with the DEC; and αT for alpha spectroscopy performed by TNT. The DEC lacked the equipment to perform alpha spectroscopy itself. Unlike gamma spectroscopy, it permits analysis of isotopes higher up the thorium and uranium chains. Alpha spectroscopy, though used for only a few samples, confirmed that the radium isotopes were present in disproportionately high amounts relative to their parent isotopes.

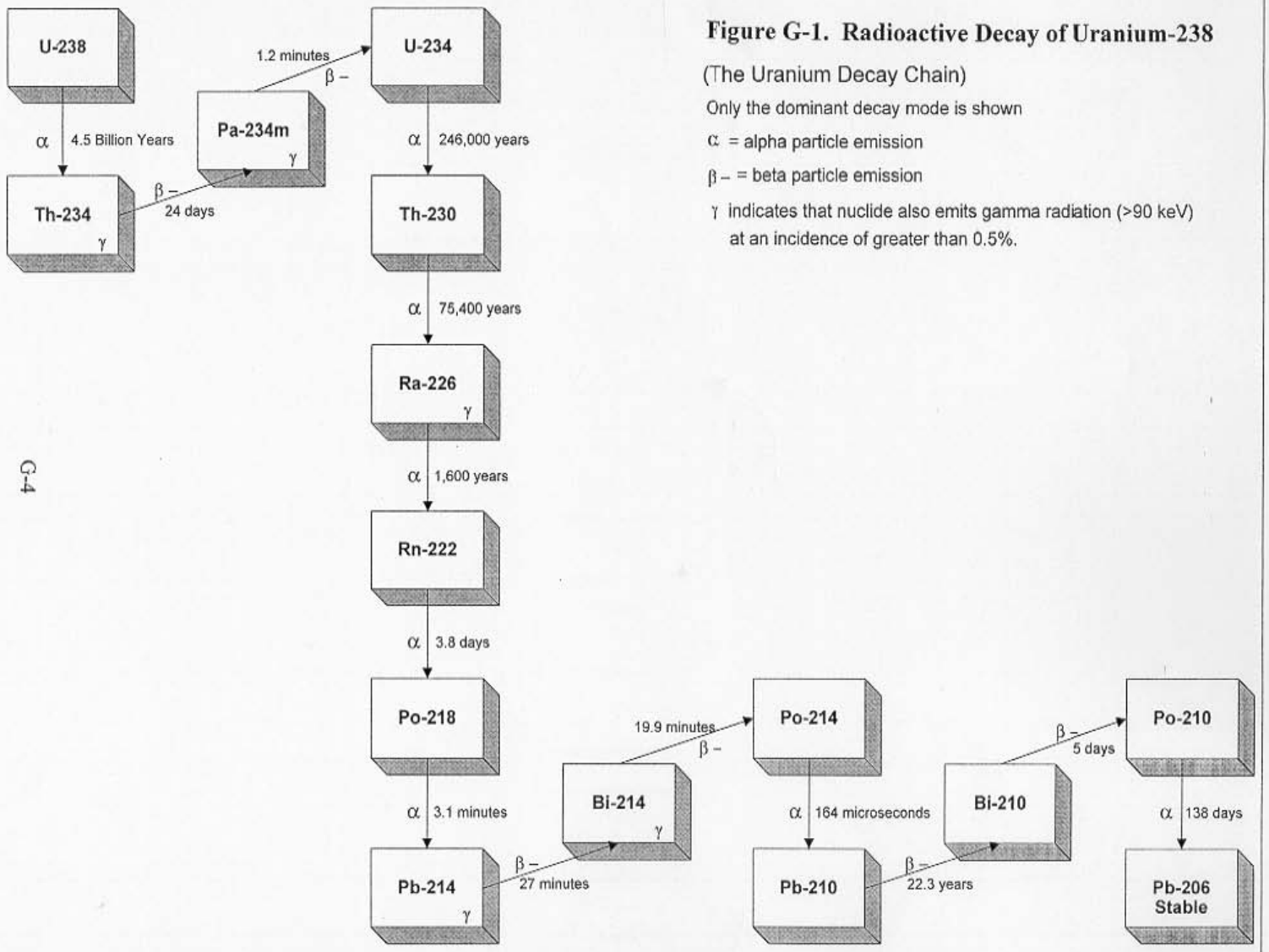


Figure G-1. Radioactive Decay of Uranium-238

(The Uranium Decay Chain)

Only the dominant decay mode is shown

α = alpha particle emission

β – = beta particle emission

γ indicates that nuclide also emits gamma radiation (>90 keV) at an incidence of greater than 0.5%.

Figure G-2. Radioactive Decay of Thorium-232

(The Thorium Decay Chain)

Only the dominant decay mode is shown

α = alpha particle emission

β – = beta particle emission

γ indicates that nuclide also emits gamma radiation (>90 keV) at an incidence of greater than 0.5%.

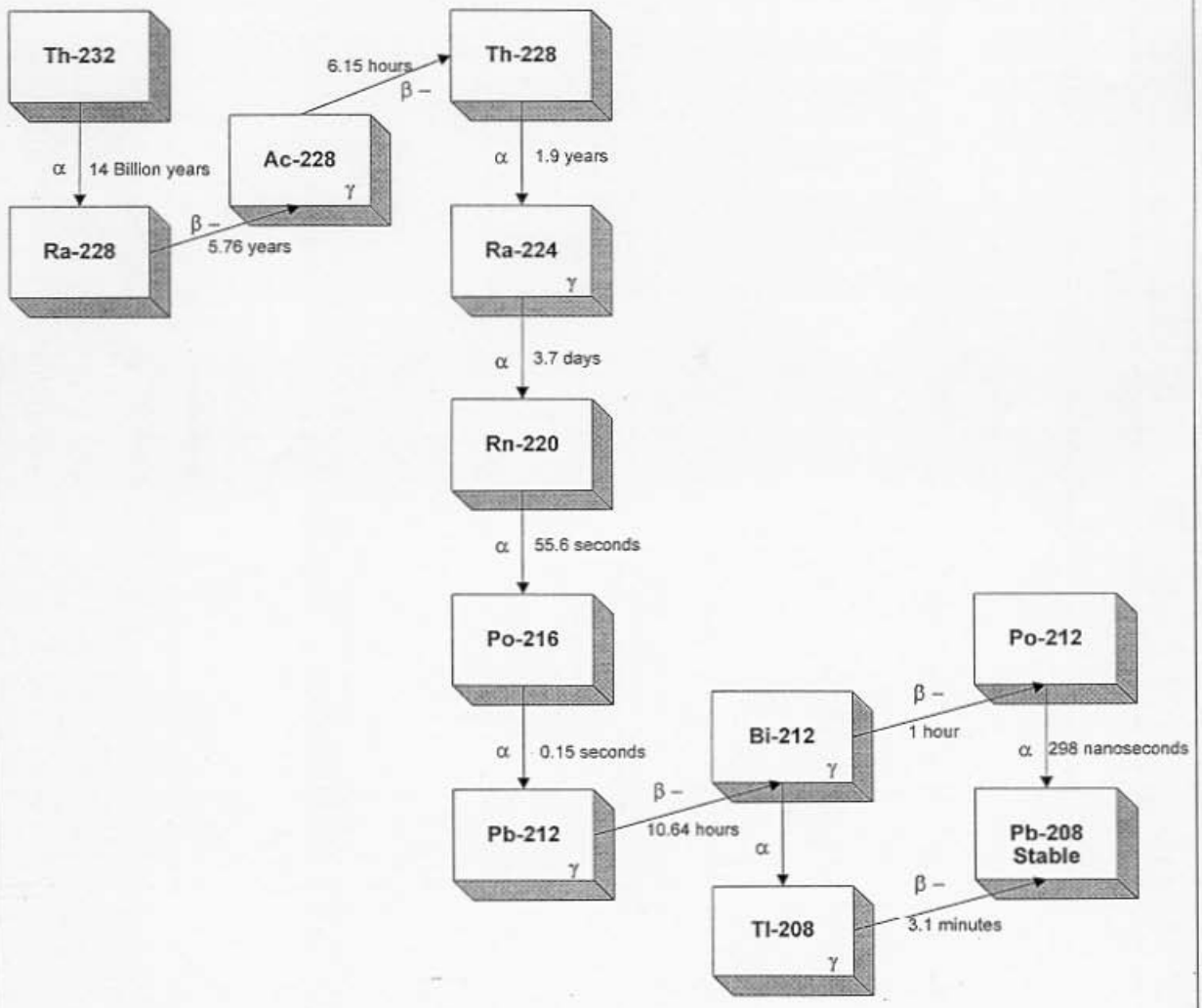


TABLE G-1. ANALYTICAL RESULTS

OG ID#	Type	URANIUM CHAIN			THORIUM CHAIN			OTHER		Units
		Ra-226	**Pb-214**	**Bi-214**	**Ac-228**	**Pb-212**	**Tl-208**	**K-40**	**Cs-137**	
071201	Water γD							2000 ±300		pCi/l
		Ra226= ND			**Ra228= ND**			**K 2000**		
071801	Brine γD		629 ±91	669 ±88	1110 ±250		39 ±24	2110 ±570		pCi/l
		Ra226 670			**Ra228 1100**			**K 2100**		
071802	Soil γD	2.64 ±0.76	0.868 ±0.089	0.766 ±0.102	1.94 ±0.17	2.69 ±0.15	0.878±0.073	16.7 ±1.4	0.101±0.037	pCi/g
		Ra226 0.9			**Ra228 2.7**			**K 17**		
071803	Soil γD		0.751 ±0.083	0.794 ±0.102	1.21 ±0.14	1.28 ±0.11	0.354±0.057	18.9 ±1.5	0.139±0.044	pCi/g
		Ra226 0.8			**Ra228 1.3**			**K 19**		
071804	Brine γD		355 ±131	402 ±68				6050 ±880		pCi/l
		Ra226 400			**Ra228 = ND**			**K 6000**		
071805	Soil γD γT	6.70 ±0.82 1.92 ±0.15	2.29 ±0.11 1.94 ±0.25	2.29 ±0.13	0.999 ±0.108	1.05 ±0.08 0.84 ±0.09	0.288 ±0.040 0.85 ±0.15	11.5 ±0.9 9.93 ±1.08	0.134 ±0.034 0.09 ±0.07	pCi/g
	αT	U238=1.1±0.4; U234=1.4±0.4; Th230=1.1±0.3			Th232=0.8±0.3; Th228=1.5±0.4					
		Ra226 2.3			**Ra228 1.1**			**K 11**		
071805D	Soil αT	U238=1.0±0.3; U234=0.8±0.3; Th230=0.8±0.3			Th232=1.1±0.3; Th228=1.5±0.2					pCi/g
		Insufficient data available for an estimate			**Insufficient data available for an estimate**					
071806	Brine γD γT	414 ±1600 460 ±20	1640 ±110 481 ±36	1760 ±130 457 ±24	420 ±210 429 ±27	250 ±46 102 ±13	68 ±29 95.6 ±16.6	1610 ±620 2670 ±150	< 10	pCi/l
	αT	U238= < 0.96; U234=1.4±1.4; Th 230=2.1±1.8; Ra 226=653±64			Th232=< 1.6; Th228= < 3					
		Ra226 1800			**Ra228 430**			**K 2700**		

TABLE G-1. ANALYTICAL RESULTS

OG ID#	Type	URANIUM CHAIN			THORIUM CHAIN			OTHER		Units
		Ra-226	Pb-214	Bi-214	Ac-228	Pb-212	Tl-208	K-40	Cs-137	
071806 D	Brine αT	Th 230=3.1±2.6; Ra226=568±56			Th232=< 1.4 Th228=< 4.5					pCi/l
		Ra226 600			**Insufficient data available for an estimate**					
071901	Brine γD	445 ±530	398 ±64	372 ±69	234 ±182			1930 ±550		pCi/l
		Ra226 390			**Ra228 230**			**K 1900**		
071902	Water γD							360 ±439		pCi/l
		Ra226 = ND			**Ra228 = ND**			**K 400**		
071903	Brine γD		259 ±47	145 ±92				3330 ±690		pCi/l
		Ra226 260			**Ra228 = ND**			**K 3300**		
071904	Brine γD		409 ±60	371 ±130				6820 ±910		pCi/l
		Ra226 410			**Ra228 = ND**			**K 6800**		
080701	Brine γD		413 ±61	339 ±129	856 ±222	319 ±55	91 ±33	554 ±457		pCi/l
		Ra226 410			**Ra228 860**			**K 600**		
080702	Brine γD		260 ±43	221 ±108	703 ±194					pCi/l
		Ra226 260			**Ra228 700**			**K = ND**		
080703	Brine γD			63 ±71				113 ±428		pCi/l
		Ra226 100			**Ra228 = ND**			**K 120**		
080704	Brine γD	152 ±358	169 ±86	154 ±90	565 ±254			210 ±142		pCi/l
		Ra226 170			**Ra228 560**			**K 210**		
080705	Brine γD		276 ±50	306 ±126	568 ±248	72 ±37		490 ±493		pCi/l
		Ra226 310			**Ra228 570**			**K 500**		

TABLE G-1. ANALYTICAL RESULTS

OG ID#	Type	URANIUM CHAIN			THORIUM CHAIN			OTHER		Units
		Ra-226	Pb-214	Bi-214	Ac-228	Pb-212	Tl-208	K-40	Cs-137	
080706	Brine γD		175 ±100	156 ±90	255 ±179			890 ±479		pCi/l
		Ra226 180			**Ra228 260**			**K 890**		
080707	Brine γD					347 ±55	105 ±32	1270 ±720		pCi/l
		Ra226 = ND			**Ra228 350**			**K=1300**		
080708	Rock γD	2.42 ±0.63	1.09 ±0.08	0.991 ±0.101	0.123±0.037	0.809±0.079	0.223±0.039	19.5 ±1.4		pCi/g
		Ra226 1.1			**Ra228 0.8**			**K 20**		
080709	Scale γD γT αT	< 2.3	1.3 ±0.2 < 1.6	0.7 ±0.4		< 0.84	< 2.4	9.8 ±2.8 1.8 ±7.6	< 0.92	pCi/g
		U238=1.5±0.5; U234=1.6±0.5; Th 230=1.3±0.4			Th232=0.3±0.2; Th228=0.5±0.3					
		Ra226 1.3			**Ra228 = ND**			**K 10**		
080710	Scale γD							69 ±40		pCi/g
		Ra226 = ND			**Ra228 = ND**			**K 70**		
080711	Scale γD		0.457±0.084	0.106±0.042	0.659±0.244	1.11 ±0.11	0.271±0.048			pCi/
		Ra226 0.5			**Ra228 1.1**			**K ND**		
080712	Brine γD		290 ±50	252 ±116	460 ±172	171 ±85	55 ±27	1380 ±560		pCi/l
		Ra226 290			**Ra228 460**			**K 1400**		
080713	Brine γD		764 ±81	598 ±175	433 ±242			3300 ±760		pCi/l
		Ra226 760			**Ra228 430**			**K 3300**		
080714	Brine γD		450 ±66	425 ±147	326 ±319	497 ±28		4810 ±840		pCi/l
		Ra226 450			**Ra228 500**			**K 4800**		

TABLE G-1. ANALYTICAL RESULTS

OG ID#	Type	URANIUM CHAIN			THORIUM CHAIN			OTHER		Units
		Ra-226	**Pb-214**	**Bi-214**	**Ac-228**	**Pb-212**	**Tl-208**	**K-40**	**Cs-137**	
080715	Brine γD		477 ±65	458 ±76	651 ±306			702 ±517		pCi/l
		Ra226 480			**Ra228 650**			**K 700**		
080716	Brine γD		708 ±71	567 ±162	350 ±297			4720 ±770		pCi/l
		Ra226 710			**Ra228 350**			**K 4700**		
080717	Brine γD		238 ±117			269 ±52		432 ±459		pCi/l
		Ra226 240			**Ra228 270**			**K 500**		
080801	Soil γD		0.901 ±0.084	0.765±0.179	1.60 ±0.15	1.57 ±0.11	0.573±0.057	26.0 ±1.6		pCi/g
		Ra226 1.0			**Ra228 1.6**			**K 26**		
080802	Soil γD	1.70 ±0.56	1.27 ±0.08	1.01 ±0.09	1.43 ±0.11	1.37 ±0.09	0.488±0.047	19.0 ±1.2		pCi/g
		Ra226 1.3			**Ra228 1.4**			**K 19**		
080803	Oil γD									pCi/l
		Ra226 = ND			**Ra228 = ND**			**K ND**		
080804	Sldg. γD γT	2.73 ±0.66 0.35 ±0.08	1.99 ±0.10 0.18 ±0.16	1.57 ±0.11	1.40 ±0.12	2.01 ±0.12 0.23 ±0.09	0.530±0.055 0.34 ±0.09	0.505 ±0.437 < 0.57	< 0.05	pCi/g
	αT	U238=0.2±0.2; U234=0.6±0.3; Th230=0.2±0.1			Th 232=< 0.1; Th228=0.6±0.3					
		Ra226 2.0			**Ra228 2.0**			**K 0.5**		
080804D	Sldg. γT	0.21 ±0.08	0.17 ±0.15			0.30 ±0.06	0.37 ±0.11	< 0.46	< 0.05	pCi/g
	αT	U238=< 0.15; U234=0.2±0.2; Th 230=< 0.1			Th232=< 0.1 Th228=0.5±0.2					
		Ra226= 0.2			**Ra228 0.4**			**K= ND**		

TABLE G-1. ANALYTICAL RESULTS

OG ID#	Type	URANIUM CHAIN			THORIUM CHAIN			OTHER		Units
		Ra-226	Pb-214	Bi-214	Ac-228	Pb-212	Tl-208	K-40	Cs-137	
080805	Soil γD	2.81 ±0.68	0.919 ±0.082	0.765 ±0.094	1.30 ±0.12	1.08 ±0.10	0.480±0.055	16.3 ±1.3		pCi/g
		Ra226 1.0			**Ra228 1.3**			**K 16**		
080806	Sed. γD	3.00 ±0.63	1.20 ±0.08	1.15 ±0.09	1.91 ±0.13	1.70 ±0.10	0.621±0.051	13.0 ±1.0		pCi/g
		Ra226 1.2			**Ra228 2.0**			**K 13**		
080807	Sed. γD		0.764 ±0.081	0.697 ±0.185	1.41 ±0.15	1.02 ±0.10	0.316±0.050	16.5 ±1.4		pCi/g
		Ra226 0.8			**Ra228 1.4**			**K 16**		
080808	Wax γD							2.21 ±2.26		pCi/g
		Ra226= ND			**Ra228= ND**			**K 2.2**		
080809	Soil γD	2.55 ±0.60	0.855 ±0.080	0.714 ±0.159	1.31 ±0.13	1.18 ±0.10	0.374±0.047	16.4 ±1.2	0.074±0.027	pCi/g
		Ra226 0.9			**Ra228 1.3**			**K 16**		
080810	Sed. γD	2.11 ±0.57	0.908 ±0.074	0.772 ±0.072	1.11 ±0.09	0.856±0.079	0.350±0.043	14.2 ±1.0	0.075±0.026	pCi/g
		Ra226 0.9			**Ra228 1.1**			**K 14**		
080811	Sed. γD	5.19 ±0.82	2.75 ±0.12	2.50 ±0.14	2.32 ±0.15	1.41 ±0.10	0.543±0.051	11.5 ±1.0		pCi/g
		Ra226 2.8			**Ra228 2.3**			**K 12**		
080812	Sldg. γD	0.956 ±0.478	0.720 ±0.072	0.853 ±0.095		0.168±0.046	0.054±0.027	0.746 ±0.441		pCi/g
		Ra226 0.9			**Ra228 0.2**			**K 0.8**		
080813	Sldg. γD γT	8.62 ±1.11 5.20 ±0.26	7.42 ±0.22 5.00 ±0.41	6.75 ±0.23	4.72 ±0.22	1.77 ±0.11 1.90 ±0.14	0.494±0.056 1.45 ±0.23	3.08 ±0.67 2.49 ±0.72	< 0.09	pCi/g
	αT	U238=0.2±0.1; U234=0.2±0.2; Th230=0.2±0.1			Th232=< 0.1; Th228=0.5±0.2					
		Ra226 7.4			**Ra228 4.7**			**K 3.1**		

TABLE G-1. ANALYTICAL RESULTS

OG ID#	Type	URANIUM CHAIN			THORIUM CHAIN			OTHER		Units
		Ra-226	**Pb-214**	**Bi-214**	**Ac-228**	**Pb-212**	**Tl-208**	**K-40**	**Cs-137**	
080814	Wax γD		0.174 ±0.092	0.130 ±0.079						pCi/g
		Ra226 0.2			**Ra228 = ND**			**K= ND**		
080815	Sldg. γD	7.11 ±1.02	6.52 ±0.20	6.22 ±0.22	4.14 ±0.20	1.55 ±0.10	0.473±0.059	3.17 ±0.65		pCi/g
		Ra226 6.5			**Ra228 4.1**			**K 4**		
080901	Rock γD	1.05 ±0.55	0.667 ±0.066			0.693 ±0.067	0.274 ±0.041	28.8 ±1.6		pCi/g
		Ra226 0.7			**Ra228 0.7**			**K 28**		
080902	Rock γD	0.705 ±0.390	0.381 ±0.051			0.288 ±0.047	0.140 ±0.032	10.3 ±1.0		pCi/g
		Ra226 0.4			**Ra228 0.3**			**K 10**		
080903	Rock γD		0.517 ±0.063			0.201 ±0.046	0.075 ±0.032	15.8 ±1.4		pCi/g
		Ra226 0.5			**Ra228 0.2**			**K 16**		
080904	Rock γD		2.44 ±0.11	2.40 ±0.14	0.642 ±0.116	0.476 ±0.054	0.148 ±0.034	13.5 ±1.2		pCi/g
		Ra226 2.4			**Ra228 0.6**			**K 14**		
080905	Rock γD		0.536 ±0.053	0.509 ±0.067		0.448 ±0.049	0.173 ±0.033	13.1 ±1.0		pCi/g
		Ra226 0.5			**Ra228 0.5**			**K 13**		
100701	Brine γD		1240 ±100	1120 ±110	1290 ±130	157 ±23	43 ±22	2420 ±720		pCi/l
		Ra226 1200			**Ra228 1300**			**K 2400**		
100702	Brine γD	1310 ±610	1070 ±80	952 ±108	1330 ±270	223 ±44	82 ±30	2840 ±670		pCi/l
		Ra226 1100			**Ra228 1300**			**K 2800**		

TABLE G-1. ANALYTICAL RESULTS

OG ID#	Type	URANIUM CHAIN			THORIUM CHAIN			OTHER		Units
		Ra-226	**Pb-214**	**Bi-214**	**Ac-228**	**Pb-212**	**Tl-208**	**K-40**	**Cs-137**	**Units**
100703	Brine γD γT	330 ±30	1070 ±90 330 ±37	1060 ±100 329 ±25	1190 ±140 1480 ±40	141 ±53 282 ±16	288 ±29	3480 ±710 3090 ±160	< 10	pCi/l
	αT	U238=<1.5; U234=<1.9; Th230=4.7±4.0; Ra226=12±6			Th232=< 3.6; Th228=20±5					
		Ra226 1100			**Ra228 1500**			**K 3500**		
100703D	Brine γT	260 ±20							< 10	pCi/l
	αT	U238= < 1.3; U234= < 1.7								
		Ra226 = ND			**Ra226 = ND**			**K=ND**		
100704	Brine γD	610 ±423	557 ±67	403 ±145	933 ±230	46 ±33		3150 ±740		pCi/l
		Ra226 560			**Ra228 930**			**K 3200**		
100705	Brine γD		465 ±65	351 ±133	977 ±230			2480 ±660		pCi/l
		Ra226 470			**Ra228 980**			**K 2500**		
100706	Brine γD							2180 ±610		pCi/l
		Ra226 = ND			**Ra228 = ND**			**K 2200**		
100707	Scale γD γT	8.36 ±1.60 9.61 ±0.67	7.12 ±0.26 10.6 ±1.00	6.46 ±0.30	2.92 ±0.24	2.45 ±0.17 3.80 ±0.35	0.642±0.0773. 3.53 ±0.54	1.24 ±0.75 < 1.46	< 0.24	pCi/g
	αT	U238=1.1±0.5; U234=4±1; Th230=0.3±0.2			Th232=<0.12; Th228=1.1					
		Ra226 11			**Ra228 3.8**			**K 1.2**		
100708	Scale γD									pCi/g
		Ra226 = ND			**Ra228 = ND**			**K= ND**		

TABLE G-1. ANALYTICAL RESULTS

OG ID#	Type	URANIUM CHAIN			THORIUM CHAIN			OTHER		Units
		Ra-226	**Pb-214**	**Bi-214**	**Ac-228**	**Pb-212**	**Tl-208**	**K-40**	**Cs-137**	
100709	Rock γD	0.396 ±0.260	0.217 ±0.079	0.121 ±0.059	0.258±0.134	0.151±0.030	0.057±0.017	3.34 ±0.46		pCi/g
		Ra226 0.2			**Ra228 0.3**			**K 3.3**		
100901	Brine γD		369 ±61	243 ±119	890 ±227	369 ±91	53 ±28	1240 ±570		pCi/l
		Ra226 370			**Ra228 890**			**K 1300**		
100902	Brine γD		538 ±72	467 ±148	625 ±207	149 ±50	78 ±31	2110 ±640		pCi/l
		Ra226 540			**Ra228 620**			**K 2100**		
100903	Brine γD		146 ±92					1990 ±620		pCi/l
		Ra226 150			**Ra228 = ND**			**K 2000**		
100904	Scale γD							0.65 ±5.17		pCi/g
		Ra226 = ND			**Ra228 = ND**			**K 1.0**		
102901	Brine γT		173 ±35	187 ±20	79.9 ±28.6	18.6 ±11.1	< 24.11	5490 ±220	< 8.90	pCi/l
		Ra226 190			**Ra228 80**			**K 5500**		
102902	Brine γT		324 ±36	304 ±25	503 ±30	80.5 ±12.6	69.3 ±21.2	1930 ±170	< 10.47	pCi/l
		Ra226 320			**Ra228 500**			**K= 1900**		
102903	Scale γT	< 6.55	< 5.99			< 3.96	< 8.01	< 23.54	< 2.81	pCi/g
		Ra226 = ND			**Ra228 = ND**			**K= ND**		
102904	Brine γT		444 ±47	406 ±34	1690 ±55	330 ±20	271 ±38	1670 ±170	<17.48	pCi/l
		Ra226 440			**Ra228 1700**			**K 1700**		
102905	Brine γD	2760 ±690	1550 ±110	1550 ±120	264 ±209	319 ±60	140 ±38	2000 ±590		pCi/l
		Ra226 1600			**Ra228 320**			**K=2000**		

TABLE G-1. ANALYTICAL RESULTS

OG ID#	Type	URANIUM CHAIN			THORIUM CHAIN			OTHER		Units
		Ra-226	**Pb-214**	**Bi-214**	**Ac-228**	**Pb-212**	**Tl-208**	**K-40**	**Cs-137**	
102906	Brine γT		366 ±45	360 ±28	1660 ±47	246 ±17	231 ±33	1700 ±160	< 14.1	pCi/l
		Ra226 370			**Ra228 1700**			**K 1700**		
102907	Brine γT		643 ±56	654 ±36	1440 ±50	114 ±17	113 ±25	1840 ±190	< 15.9	pCi/l
		Ra226 650			**Ra228 1400**			**K 1900**		
102908	Oil γT		< 19.2			140 ±18	76.6 ±25.9	55.7 ±93.7	< 10.8	pCi/l
		Ra226 = < 20			**Ra228 140**			**K 100**		
102909	Brine γT		1040 ±40	1020 ±34	387 ±32	678 ±20	566 ±33	2380 ±180	< 11.6	pCi/l
		Ra226 1000			**Ra228 680**			**K 2400**		
102910	Sldg. γT	2.09 ±0.2	1.99 ±0.32			2.18 ±0.15	1.88 ±0.23	0.85 ±0.78	< 0.08	pCi/g
	αT	U238=0.4±0.4; U234=1.0±0.6; Th230=0.3±0.3			Th 232=< 0.3; Th 228= 3.2±1.1					
		Ra226 2.0			**Ra228 2.2**			**K 0.8**		
102911	Scale γT	< 0.18	0.18 ±0.19			< 0.10	< 0.18	0.66 ±0.63	< 0.07	pCi/g
		Ra226 0.2			**Ra228 < 0.2**			**K 0.7**		
102912	Scale γT	< 0.27	0.22 ±0.24			< 0.12	0.25 ±0.15	0.87 ±0.48	< 0.08	pCi/g
		Ra226 0.2			**Ra228 = 0.3**			**K 0.9**		
102913	Scale γT	< 1.08	0.96 ±1.19			< 0.61	< 1.59	< 4.70	< 0.45	pCi/g
		Ra226 1			**Ra228 = < 0.6**			**K 4.7**		
102914	Scale γT	1.10 ±0.43	1.08 ±0.79			0.56 ±0.25	0.87 ±0.53	3.12 ±2.84	< 0.21	pCi/g
		Ra226 1.1			**Ra228 0.9**			**K 3.1**		

TABLE G-1. ANALYTICAL RESULTS

OG ID#	Type	URANIUM CHAIN			THORIUM CHAIN			OTHER		Units
		Ra-226	**Pb-214**	**Bi-214**	**Ac-228**	**Pb-212**	**Tl-208**	**K-40**	**Cs-137**	
102915	Wax γT					< 0.16	< 0.34	1.07 ±0.85	< 0.21	pCi/g
		Ra226 = ND			**Ra228 < 0.3**			**K 1.1**		
103001	Brine γT		64.2 ±27.2	60.5 ±23.1	< 39.26	83.1 ±12.4	54.6 ±23.5	2240 ±190	< 10.79	pCi/l
		Ra226 64			**Ra228 83**			**K 2300**		
103002	Brine γT		143 ±25	148 ±17	100 ±23	32.8 ±8.9	19.7 ±18.3	1190 ±130	< 7.63	pCi/l
		Ra226 150			**Ra228 100**			**K 1200**		
103003	Brine γT		160 ±35	111 ±22	574 ±31	103 ±14	96.7 ±24.4	714 ±114	< 10.46	pCi/l
		Ra226 160			**Ra228 570**			**K 710**		
103004	Brine γT		182 ±26	185 ±20	86.4 ±25.2	356 ±18	228 ±21	217 ±94	< 9.45	pCi/
		Ra226 190			**Ra228 360**			**K 220**		
103005	Brine γT		953 ±64	949 ±40	444 ±45	247 ±19	242 ±36	3010 ±260	< 16.75	pCi/l
		Ra226 950			**Ra228 440**			**K 3000**		
103006	Sldg. γD		0.234 ±0.111					0.977 ±0.684		pCi/g
		Ra226 0.2			**Ra228= ND**			**K 1.0**		
103007	Wax γD γT	< 0.46	0.235 ±0.1.37 < 0.33	0.159 ±0.140		< 0.25	< 0.45	1.99 ±1.29	< 0.20	pCi/g
	αT	U238=< 0.12; U234=0.15±0.12; Th 230=0.5±0.3			Th 232=< 0.15; Th 228=< 0.2					
		Ra226 0.2			**Ra228= ND**			**K 2.0**		
103007 D	Wax γT	< 0.38	< 0.33			< 0.26	< 0.54	2.0 ±1.3	< 0.19	pCi/g
		Ra226 < 0.4			**Ra228 < 0.5**			**K 2.0**		

TABLE G-1. ANALYTICAL RESULTS

OG ID#	Type	URANIUM CHAIN			THORIUM CHAIN			OTHER		Units
		Ra-226	Pb-214	Bi-214	Ac-228	Pb-212	Tl-208	K-40	Cs-137	
103008	Wax γD					0.091±0.094				pCi/g
		Ra226 = ND			**Ra228 0.1**			**K= ND**		
103009	Sldg. γD		0.598 ±0.069	0.491 ±0.152		0.155±0.046		0.532 ±0.487		pCi/g
		Ra226 0.6			**Ra228 0.2**			**K 0.5**		
103010	Brine γD		585 ±67	472 ±138				1020 ±520		pCi/l
		Ra226 590			**Ra228 = ND**			**K 1000**		
103011	Brine γD		858 ±109	951 ±109	1500 ±170	23900 ±700	7580 ±220	1180 ±600		pCi/l
		Ra226 950			**Ra228 24,000**			**K 1200**		
103012	Brine γT		442 ±49	484 ±32	1420 ±50	259 ±17	227 ±31	1500 ±170	< 15.29	pCi/l
		Ra226 480			**Ra228 1420**			**K 1500**		
103013	Brine γT		156 ±35	147 ±25	504 ±36	648 ±26	353 ±32	1040 ±150	< 12	pCi/l
		Ra226 160			**Ra228 650**			**K 1100**		
103101	Brine γT		114 ±37	100 ±18	100 ±33			4060 ±230	< 11.6	pCi/l
		Ra226 110			**Ra228 100**			**K 4100**		
103101 D	Brine γT		107 ±33	72.9 ±20.3		18.6 ±13.2		3820 ±230	< 11.36	pCi/l
		Ra226 110			**Ra228 19**			**K 3800**		
103102	Water γT		< 16.3	< 16.7	< 28.8	< 11.2	< 20.7	< 71.2	< 8.2	pCi/l
		Ra226 < 20			**Ra228 < 30**			**K < 70**		

TABLE G-1. ANALYTICAL RESULTS

OG ID#	Type	URANIUM CHAIN			THORIUM CHAIN			OTHER		Units
		Ra-226	**Pb-214**	**Bi-214**	**Ac-228**	**Pb-212**	**Tl-208**	**K-40**	**Cs-137**	
103103	Sed. γD γT	7.79 ±1.02 6.16 ±0.32	5.97 ±0.19 6.45 ±0.49	5.51 ±0.20	4.20 ±0.20	1.19 ±0.09 2.06 ±0.17	0.383±0.049 1.64 ±0.25	3.81 ±0.65 5.61 ±1.30	< 0.12	pCi/g
	αT	U 238=1.2±0.4; U234=1.1±0.4; Th 230=1.5±1			Th 232=2.3±1.2; Th 228=6.3±2.8					
		Ra226 6.5			**Ra228 4.2**			**K 5.6**		
103104	Sed. γT	4.84 ±0.29	5.48 ±0.42			2.93 ±0.19	2.41 ±0.28	10.1 ±1.6	< 0.12	pCi/g
		Ra226 5.5			**Ra228 3.0**			**K 10**		
103105	Sldg. γD		3.99 ±0.16	3.68 ±0.18	2.89 ±0.18	1.36 ±0.10	0.432±0.058	4.15 ±0.71		pCi/g
		Ra226 4.0			**Ra228 2.9**			**K 4.2**		
110101	Sed. γT	1.04 ±0.21	1.33 ±0.40			1.39 ±0.17	1.37 ±0.27	10.0 ±1.6	< 0.12	pCi/g
		Ra226 1.3			**Ra228 1.4**			**K 10**		
110101 D	Sed. γT	1.07 ±0.24	1.23 ±0.30			1.64 ±0.17	1.44 ±0.27	10.7 ±1.5	< 0.12	pCi/g
		Ra226 1.2			**Ra228 1.6**			**K 11**		
110103	Sed. γT	0.51 ±0.14	0.57 ±0.22			0.42 ±0.10	0.39 ±0.16	3.15 ±0.93	0.12 ±0.08	pCi/g
		Ra226 0.6			**Ra228 0.4**			**K3.2**		
110104	Wax γT	< 0.10	< 0.10			< 0.07	< 0.14	< 0.53	< 0.04	pCi/g
		Ra226 = ND			**Ra228 = ND**			**K 0.5**		
110105	Brine γT	*NR	1010 ±60	892 ±38	231 ±35	< 21.4	35.8 ±22.6	3320 ±200	7.28 ±4.04	pCi/l
		Ra226 1000			**Ra228 230**			**K 3300**		
110105 D	Brine γT	*NR	791 ±44	746 ±31	269 ±48	< 20.4	37.8 ±22.6	3430 ±240	< 12.3	pCi/l
		Ra226 790			**Ra228 270**			**K 3400**		

TABLE G-1. ANALYTICAL RESULTS

OG ID#	Type	URANIUM CHAIN			THORIUM CHAIN			OTHER		Units
		Ra-226	Pb-214	Bi-214	Ac-228	Pb-212	Tl-208	K-40	Cs-137	
110106	Brine γT	*NR	690 ±44	691 ±26	154 ±30	76.7 ±12.4	87.8 ±22.4	1520 ±140	< 9.17	pCi/l
		Ra226 690			**Ra228 150**			**K 1500**		
120501	Brine γT	*NR	3760 ±100	3440 ±70	1110 ±60	7650 ±70	7290 ±110	1510 ±320	< 24.99	pCi/
		Ra226 3800			**Ra228 7700**			**K 1500**		
120502	Brine γT	*NR	1410 ±80	1620 ±110	1790 ±60	235 ±21	236 ±35	2200 ±220	< 19.01	pCi/l
		Ra226 1600			**Ra228 1800**			**K 2200**		
041501	Lab Water, γD	-	-	-	Peaks	Detected	-	-	-	pCi/g
041502	Lab Soap & Water, γD	-	-	-	Peaks	Detected	-	-	-	pCi/g

* Ra-226 and U-235 have a conflicting gamma peak at 186 keV. The γT analytical results list the result as U-235; it is more likely Ra-226 though not reported as such.

REFERENCES

API 1993. A National Survey on Naturally Occurring Radioactive Materials (NORM) in Petroleum Producing and Gas Processing Facilities. Dallas, TX: American Petroleum Institute, July 1989.

Dahl 1990. "Radioactivity in Oil/Gas Production Fields," a NYSDEC DMN internal memorandum from Jack Dahl to Greg Sovas.

Eisenbud 1987. Eisenbud, Merril. Environmental Radioactivity From Natural, Industrial and Military Sources, 3rd Edition, New York: Academic Press, Inc., 1987.

Escott 1984. Escott, P. "The Occurrence of Radioactive Contamination on Offshore Installations." NRPB report for the Department of Energy London, 1984.

Fitzpatrick 1989. Fitzpatrick, Kathleen. Water Produced with Oil and Gas in New York State: 1987 Year-End Volumes and Disposal Methods. April 11, 1989.

Merges 1990. "Oil and Gas Field Radioactive Scale," a NYSDEC internal Memorandum from Paul J. Merges to John Harmon and Peter Buechi.

NYSDEC 1988. New York State Department of Environmental Conservation, Division of Mineral Resources. Draft Generic Environmental Impact Statement on the Oil, Gas and Solution Mining Regulatory Program. January 1988.

NYSDEC 1993. New York State Department of Environmental Conservation. DHSR TAGM 4003: Cleanup Guideline for Soils Contaminated with Radioactive Materials. September 14, 1993.

NYSDEC 1997. New York State Department of Environmental Conservation, Division of Mineral Resources. New York State Oil and Gas Drilling and Production and Mineral Resources 1996, August 1997.

PDER 1994. Pennsylvania Department of Environmental Resources, Bureau of Oil and Gas Management, Characterization and Disposal Options for Oil field Waste in Pennsylvania. June 1994.

Smith 1987. Smith, A.L. "Radioactive-Scale Formation," Journal of Petroleum Technology. June 1987, pp. 697-705.

USEPA 1993. United States Environmental Protection Agency, Office of Radiation and Indoor Air. Diffuse NORM Wastes - Waste Characterization and Preliminary Risk Assessment. April 1993.

Waldram 1998. Waldram, I.M. "Natural Radioactive Scale: The Development of Safe Systems of Work," Journal of Petroleum Technology. August 1988, pp. 1057-1060.

Wilson 1992. Wilson, A.J. and L. Max Scott. "Characterization of Radioactive Petroleum Piping Scale with an Evaluation of Subsequent Land Contamination," Health Physics, December 1992, Volume 63, Number 6, pp. 681-685.