

TENORM Study Scope of Work

Throughout Pennsylvania many companies perform oil and gas exploration and production activities by conventional and unconventional drilling through various subsurface layers of shale and rock to produce oil and natural gas. The drilling industry production and flowback water, as well as drill cuttings and sources of off gassing (e.g. drill cuttings), are potentially impacted with naturally occurring radioactive material (NORM) and/or technologically enhanced naturally occurring radioactive material (TENORM). The proposed comprehensive study will focus on the quantification of TENORM in:

- Ambient air;
- Drill cuttings (vertical and horizontal);
- Natural gas;
- Natural gas processing pipes and equipment;
- Waste water generated on drilling sites;
- Sludge resulting from the processing of waste water from the well pad development process;
- Landfill leachate.

In addition, a literature search of data on all relevant geological formations and currently available TENORM data will be included in the study as well as sampling of applicable areas potentially impacted through beneficial reuse of brine and other materials. This proposal includes all labor, equipment and travel costs associated with this effort including the development of a specific Sampling and Analysis Plan (SAP). The sampling and analysis, site surveying and data management activities will be conducted by Perma-Fix Environmental Services, Inc. (PESI) in conjunction with PA DEP. A final report, including an assessment of potential pathways for human exposure to radioactive material, will be prepared by PA DEP and PESI. The SAP will include both a Field Sampling Plan (FSP) that provides the details of the survey and sample protocols to be used and a Quality Assurance Project Plan (QAPP) that provides details of the laboratory analytical methods; the quality control of both field instruments and laboratory equipment; and the quality control program, which includes establishing reference background samples (where appropriate), blank analyses, duplicate analyses and spike analyses (where possible and applicable).

Previously collected unconventional drilling process water sample analytical results show measurable concentrations of radium-226 (Ra-226). Radium-226 is a common NORM radionuclide and the element associated with the natural decay series with the most mobility. Because NORM is most likely associated with various geologic units, the scope of work presented herein will focus on these units and the operations, equipment and features related to the drilling and production of natural gas from these geologic units and also in the transfer of water to public or privately owned wastewater treatment plants (POTWs), centralized wastewater treatment (CWT) facilities, and zero liquid discharge (ZLD) facilities for processing. Landfill

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leachate will also be sampled to study whether Ra-226 has migrated from waste water treatment plant sludge to the landfill leachate. Any beneficial reuse of any of the oil and gas drilling production media will also be surveyed and sampled as appropriate. Other types of samples to be collected will include but are not limited to:

- Vertical and horizontal drill cuttings;
- Onsite pits containing cuttings;
- Production water;
- Flowback water;
- Filter socks;
- Filter presses;
- Compressed gas lines;
- Off gassing;
- Well pads;
- Centralized impoundments;
- Waste water facility sludge;
- Waste water facility influent and effluent water;
- Piping and casing scale;
- Vapor capture systems;
- Fresh proppant sands; and
- Drilling muds.

It is important to understand the movement and exposure pathways of NORM/TENORM through the entire oil and gas exploration and production process in the Commonwealth of Pennsylvania. In this regard, we propose this comprehensive study to provide a more complete understanding of NORM/TENORM in the oil and gas industry and waste disposal operations, and to document and evaluate potential radiation exposure pathways to workers and the public, as well as to ensure protection of the environment.

The following tasks will be completed in support of the study:

1. Develop a Sampling and Analysis Plan (SAP) – An SAP consisting of a Field Sampling Plan (FSP) and a Quality Assurance Project Plan (QAPP). The FSP will detail the actual sampling including types, quantities, chain of custody, sample technique, specific analyses, etc. The QAPP will detail the quality assurance and control associated with all of the sampling and analytical techniques to be used including blanks, splits, spikes and duplicate analyses. The plan will be submitted to the PA DEP for review and comment before finalizing. A draft Gas Well Flow Back Water Sampling and Analysis Program is attached to this proposal as an example of the survey and sample detail to be included. An independent peer review of the SAP is included.

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2. Exploration and Production Site Survey and Sampling – The study will include survey and sample events on active and inactive drill sites, including:
 - a. Open/Operating Cuttings Pits – Radiological characterization will include field screening (exposure rates/gross gamma activity) of the cutting pit areas or disposal containers using portable survey meters and the sampling and laboratory analysis of the drill cuttings stored in the open/operating pits or containers. The sampling and analysis of the drill cuttings (solid material) will assist in determining radiological isotopes of concern and in evaluating their potential mobility in the environment.
 - b. Closed/Reclaimed Cuttings Pits – If present, radiological characterization will consist of field screening (exposure rate/gross gamma activity) using portable survey meters to evaluate the potential for elevated radiological activity (above a background reading from a non-impacted site location) at the ground surface above the closed/reclaimed pits.
 - c. Sample and analyze fresh proppant sands, drill muds, flowback and produced water on sites in accordance with the SAP. Evaluate solid and aqueous phases separately as specified in this program.
 - d. Temporary Water Storage Vessels and Recycle Systems (Hydraulic Fracturing Water Storage Tanks, Produced Fluids Tanks, Filtration Equipment, Water Trucks)
 - i. Exposure Rate/Gross Gamma Activity survey of temporary water storage vessels to identify potential areas of NORM/TENORM.
 - ii. Collect and screen samples of solids accumulated in vessels for gross activity.
 - iii. Collect swipe (smear) samples to determine removable surface contamination in units of disintegrations per minute per 100 centimeters squared (dpm/100cm²). Removable surface activity is an indicator of potential airborne exposure through inhalation and/or ingestion of removable contamination.
 - e. Drilling Rigs and Associated Equipment
 - i. Structural surface survey of drilling rigs and equipment to identify the possible presence of NORM/TENORM. The survey will consist of scanning with portable survey meters for gross gamma activity and/or

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total surface contamination (dpm/100cm²) and collecting swipe (smear) samples to determine removable surface contamination (dpm/100cm²). Total contamination is the sum of fixed and removable contamination. As mentioned above, removable surface activity is an indicator of potential airborne exposure through inhalation and/or ingestion of removable contamination.

- ii. Collect and screen samples of solids (scale) accumulated on rigs, pipes, used well casings and associated equipment.
 - iii. PESI will coordinate with PA DEP radon division and well operators to perform radon sampling of gas as appropriate.
- f. Offices, Office Trailers, Trucks, etc.
- i. Instrument surveys (exposure rate, gross gamma and/or total contamination) of offices, trailers, trucks, etc., to identify areas where NORM/TENORM may be present.
 - ii. Collect swipe (smear) samples to determine removable surface contamination.
- g. Production Equipment (Separators, Heater/Treaters, Dehydration Units, Flares, Compressors)
- i. Instrument surveys (exposure rate, gross gamma and/or total contamination) of production equipment to identify potential areas where NORM/TENORM may be present.
 - ii. If possible, collect and screen samples of solids and/or liquids accumulated in/on production equipment.
 - iii. If possible, collect swipe samples to determine removable surface contamination.
 - iv. PESI will coordinate with PA DEP radon division and well operators to perform radon sampling of gas as appropriate.

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3. Waste Water Facilities Sampling and Analysis

- a. Twenty-two (22) of the highest volume Marcellus shale waste water treatment facilities will be included in this study. Sixteen (16) are located in the Western sector of Pennsylvania. The other six (6) are located in the Central sector. Facilities will include POTWs, CWTs, ZLDs and specialized Marcellus shale water treatment operations.
- b. Each of the 22 waste water treatment facilities will be sampled as often as three (3) times to establish a trend.
- c. A total of three to four (3-4) media samples will be taken at each facility during each of the 3 sample events: influent Marcellus shale industry water, facility effluent discharge water, sludge from the treatment of the water and sediments at the effluent discharge point where applicable.
- d. PESI will perform a gamma exposure rate survey at the facility each time a sample event occurs. Gross gamma radiation will be measured on the outside of sludge tanks as access allows, at the effluent discharge point and around the incoming waste water truck if available.
- e. PESI will record any other pertinent data during each sample event, e.g., influent volume from Marcellus shale, total influent flow, effluent flow. To the extent possible PESI will coordinate the sampling of the influent water, the sludge and the effluent water with the facilities such that the samples are all related to the processing of the influent Marcellus shale industry water.
- f. Each of the samples will be analyzed for gross alpha and beta and by gamma spectroscopy to identify TENORM radionuclides.
- g. Approximately 10% of the samples, based on the gross alpha and beta, and gamma spectroscopy results, will also be analyzed by alpha spectroscopy for uranium (U-238, U-235 and U-234), thorium-232, radium (Ra-226 and Ra-228) and for any unsupported decay chain radionuclides; and for radon (Rn-220 + Rn-222).
- h. Sampling and analyses will be coordinated and performed by PESI, through the Beaver, PA office. This work will be accomplished in accordance with the Sampling and Analysis Plan (SAP) developed by PESI and approved by PA DEP.
- i. Facilities located throughout PA will be surveyed and sampled per the schedule jointly developed by PA DEP and PESI. Two PESI field technicians will travel to

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- each facility with up to two PA DEP field staff. Day trips will be utilized when cost effective.
- j. For facilities located in the Central sector of PA, the two field technicians will travel to each facility and require overnight trips.
 - k. Each sample will be surveyed for gross gamma radiation and loose alpha and beta surface contamination. The sludge within the facility will also be surveyed for gross gamma activity at the time the sample is taken.
 - l. In addition to the media sampling, indoor radon gas measurements will also be performed within any buildings, trailers or enclosures where personnel occupancy is required.
 - m. Samples will be packaged and delivered to either an appropriate radiochemistry laboratory or the PA DEP Laboratory for the analyses.
 - n. Based on the results of the first round of waste water treatment plant sampling, loads of sludge from selected facilities will be followed to the landfill disposal sites and resampled to evaluate the effects of the transportation of that material as part of the second round of sampling of these facilities.
 - o. Survey and analytical data will be reviewed and validated by a radiological engineer. The data will be compiled in tables and trended as appropriate.
 - p. A final report specific to waste water treatment facilities will be prepared and submitted to PA DEP for review and comments. The report will include the sampling protocol, the data presentation, the data review and assessment and recommendations.
4. Landfills
- a. Landfill Leachate - Landfill leachate will be sampled at each of the 54 active landfills and analyzed for gross alpha/beta and Ra-226/Ra-228 by gamma spectroscopy to evaluate the effects of NORM/TENORM disposal on leachate quality.
 - b. TENORM Disposal - PESI will conduct field sampling at nine (9) landfills to include ambient measurements, solid samples and sweeps of facilities and equipment at entry points to the facilities, the working faces and other areas potentially affected during disposal activities.

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5. Beneficial Reuse – areas adjacent to road beds where brine has been used will be surveyed for residual NORM/TENORM and sampled as appropriate. Facilities or sites utilizing vertical rock cuttings will be surveyed for ambient gamma radiation.
6. Gas Processing and Distribution
 - a. Natural gas samples will be taken and tested for radon at compressor stations, storage facilities, processing facilities and end users such as natural gas fueled power plants.
 - b. Ambient gamma radiation will be measured within these facilities.
 - c. Ambient radon sampling will also be conducted in these facilities due to the possible presence of radon in the gas.
7. Data Assessment, Exposure and Pathway Analysis and Final Report – PESI will receive, review and validate all of the survey and analytical data generated as part of the study. The data will be used to evaluate potential exposure through various environmental and occupational pathways, and a final report will be prepared including the following:
 - PESI will compile all of the survey data and the results of all laboratory analyses and compile in tables including the activity, uncertainty and minimum detectable concentration (MDC) values for each parameter measured.
 - An evaluation of the average and maximum activity concentrations within each media sampled. Activity concentrations will be compared to relevant and potentially appropriate criteria including US Department of Transportation (DOT) values for transporting NORM/TENORM without labeling as radioactive material, e.g. 270 pCi/g for solid material, EPA Drinking Water Standards, 10 CFR 20 Effluent Discharge for Air and Water values and federal and state public exposure criteria.
 - An evaluation of all potential exposure pathways, both internal and external, including radon, based on survey and sample analysis results for drilling sites as well as waste water facilities.
 - An evaluation of all byproducts of the oil and gas production industry including crystalline salts from the evaporation of brine water and the sludge associated

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with the flocking of process and flowback waters impacted with solids, in regards to worker exposure, public exposure and future exposure from the disposal of the products.

- An assessment of secular equilibrium for the full uranium and thorium natural decay series as well as the Ra-226 and short-lived progeny sub-series, including the rapid buildup of radon and progeny in samples/waste streams impacted with radium. The evaluation of waste containing Ra-226 is subject to the buildup of radon gas and the other short-lived progeny of Ra-226, complicating any decision made to transport or dispose of such materials based on an exposure rate survey of the container. The exposure rate is directly proportional to the degree of secular equilibrium and NOT proportional to the activity concentration of Ra-226 (remains the same as radon and other progeny buildup).
- An assessment of the current landfill conceptual model used to determine the DEP blanket authorization activity and quantity for disposal of TENORM in the Commonwealth municipal landfills. The RESRAD software code will be used to model the standard landfill future exposure through environmental pathways.

An independent peer review of the report will be conducted prior to the finalization of the report.

The majority of samples will be forwarded to the PA DEP Laboratory for analysis. A fraction of the samples, i.e., 10%, will be forward to an independent contracted laboratory for quality control/assurance.

The scope / survey and sampling may be adjusted as necessary after the initiation of the field work.