Understanding and Managing the Radiological Issues Associated with the Hydraulic Fracturing for Oil and Gas – 14600

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ABSTRACT

It is expected that the worldwide hydraulic fracturing 'fracking' market will grow to an estimated $64 Billion in 2017. Technological advancements in the past twenty years have facilitated the recent boom in fracking for oil and gas, a method that has fallen under intense public scrutiny. Fracking is a technique that injects pressurized fluid into rock layer to propagate fractures that allows natural gas and other petroleum products to be more easily extracted. As a result of the recent boom, the presence of radioactivity and radioactive materials associated with the oil and gas industry has become a public and worker health concern with potential for new regulations associated with their handling and disposal.

Long before the recent boom in the use of fracking to extract oil and gas, the oil and gas industry has been dealing with radiological issues. In fact, the industry has relied on radioactivity, both natural and artificial (man-made) for decades to aid in exploration, well development, and product distribution. Because there are naturally-occurring radioactive materials (NORM) in the media surrounding and containing oil and gas deposits, the process of fracking can dislodge radioactive materials and transport them to the surface in the solids, liquids, and gases. Various processes during the production of oil and gas and including processes to treat the wastewater can concentrate the NORM into technologically-enhanced NORM (TENORM). Existing regulations to classify, transport, and dispose of the NORM and TENORM and other radioactive waste can be complicated and cumbersome and vary widely in the international community and even between states. In fact, regulations on NORM and TENORM do not exist in many cases.

Public scrutiny and regulator pressure will only continue to increase as the world demands on oil and gas rise and greater quantities of NORM and TENORM materials are produced. Oil and gas industry experts, radiation protection experts, regulatory bodies, and public communities must work together to understand and manage radiological issues to ensure reasonable and effective regulations protective of the public, environment, and worker safety and health are implemented.

INTRODUCTION

The oil and gas industry has been dealing with radiological issues long before the recent boom in the use of hydraulic fracturing ‘fracking’ to extract oil and gas. In fact, the industry has relied on radioactivity for decades to aid in exploration, well development, and product distribution. Technological advancements in the past twenty years have provided a recent boom in fracking for oil and gas, a method that has fallen under intense public scrutiny. As a result, the presence of man-made and natural radioactivity and radioactive materials associated with the oil and gas industry has become a public and worker health concern with potential for new regulations associated with their handling and disposal.

DESCRIPTION

Hydraulic Fracturing

Hydraulic fracturing is a technique that utilizes pressurized liquid injected into rock formations to create fractures releasing petroleum and natural gas products. Constraints in vertical drilling or “conventional” drilling did not allow for sufficient oil and gas recovery from rock formations such as shale, located several thousand feet below the surface, and with a relatively narrow vertical profile. Recent technological advances, particularly involving chemical additives to the fracking fluids, and advances in horizontal drilling techniques have opened up a massive shale oil and gas market previously not financially viable. Starting with a vertical well curved in a horizontal or lateral direction extending parallel with the rock formations, lateral profile hydraulic fracturing in this configuration is significantly more effective in recovering the natural gas and oil deep below the earth’s surface. Upon termination of the horizontal well drilling, high pressure fracture fluid, consisting primarily of water, gel, sand, and various proprietary chemical additives, is pumped into the rock formation inducing fractures. Once the fracturing is complete, the fracture fluid flows back through the well, known as the “flowback” or “produced” water, consisting of the ingredients included in the injection fluid cocktail along with minerals and natural formation water. After a successful rock fracture the natural gas and oil flows up to the well head for testing and eventual production.

Worldwide Market

Although North American revenues accounted for 87 percent of the fracking market [1], the worldwide market for hydraulic fracking grew to an estimated $37 billion in 2012 [1]. North American fracking activities in Canada and the United States (U.S.) focus heavily on shale formations including the Bakken formation in North Dakota and Montana, the Marcellus and Utica formations in Pennsylvania and West Virginia, the Haynesville formation in Louisiana and Texas, and the Montney formation in Canada. In late 2012, Britain’s government lifted its ban to prohibit hydraulic fracturing resulting in increased oil and gas exploration in the United Kingdom (UK). Additional international interest in hydraulic fracturing in Australia, China, Poland, and India is expected to continue to provide future expansion of the worldwide market to an estimated $64 billion by 2017.

Controversy

Hydraulic fracturing has been met with intense public scrutiny due to the potential environmental hazards. In addition to the environmental concerns previously associated with oil and gas drilling activities, public and regulatory concerns involving seismic activity, fracturing fluid waste, and water contamination from fracking receive a significant amount of the negative attention. Typically the specific chemical components added to the fracture fluid are considered proprietary and are withheld from public discourse aiding in the distrust between the industry and the public. Even Hollywood hype surrounding fracking has grown due to recent film releases including “Gasland”, “Promised Land”, and “Gasland II”. The oil and gas industry’s response included a campaign to “debunk” Gasland by issuing documents, websites, and media releases. New York State (NY) recently extended their statewide moratorium on hydraulic fracturing; although natural gas produced using fracking in the neighboring State of Pennsylvania (PA) is piped into NY with ongoing construction to support greater transportation capacity of the gas from PA into NY.

Historical Uses of Radioactivity

Radioactivity has long been used by the oil and gas industry to aid in exploration, well development, and product distribution. Operators commonly utilize industrial radiography services to ensure the required quality standards are met during construction and fabrication of oil and gas systems. Due to high physical forces imposed on drilling components (such as the pressure imposed during fracking) welds can be inspected with radiography devices. Another use of radioactivity in the industry is to incorporate a radioactive source in a pipeline pig. Periodically plastic or rubber plugs (pigs) are forced through oil and gas pipelines to remove solid deposits that impede product flow. The pig is loaded with a radioactive source to aid in locating the pig if it becomes stopped or to help locate a leak in the pipeline as the pig passes through. Nuclear density gauges are also commonly used by the industry. The gauges can be installed on pipelines or vessels to monitor or aid in controlling the density of fluid flowing through pipelines or to measure fluid levels in vessels.

Radioactive tracers (radiotracers) play a significant role in the oil and gas industry. Radiotracers help during critical operations including calculating well flow rates, and are frequently a component of the injection fluid used to determine the injection profile and locations of fractures. Typical gamma- or beta- emitting radioisotopes include radionuclides of antimony, argon, bromine, iodine, manganese, strontium, technetium, and xenon. Depending on the needs of the study, the selection of the radiotracer is partly determined by its half-life and partly by its decay type. For example, argon-41 (Ag-41), a common radiotracer, is a pure beta emitter with a half-life of 109 minutes [2]. Another common radiotracer, iridium-192 (Ir-192) is a longer-lived radionuclide that emits gamma and beta radiation with a half-life of 74 days [2]. Typically radioactive tracers have short half-lives so that they rapidly decay to stable isotopes after the study is performed.

Multiple types of nuclear logging techniques are used to measure the properties of the rock in a well as a means to identify rock density, porosity, and isotope content. One technique emits neutrons in an outward direction and measures the backscattered neutrons to determine the porosity index for the rock. A second technique measures the radioactivity emitted from nuclides that may have become radioactive when hit by the neutrons (activated) to identify the isotopes present in the rock. A third logging technique records and identifies the natural radioactivity present in the rock through the use of spectroscopy to aid in well mapping.

NATURALLY OCCURRING RADIOACTIVE MATERIALS

Oil and gas deposits exist in geologic formations that contain naturally-occurring radioactive materials (NORM), particularly the radionuclides associated with the thorium (Th-232) and uranium (U-238) decay series. The radioactive decay progeny of these series (shown in Table I and Table II) exist in secular equilibrium in the rock of the earth’s crust. Geologists have recognized that the presence of these NORM nuclides, including radium (Ra-226) and radon (Rn-222) may be indicative of the existence of a petroleum deposit. Many of the petroleum deposits in the earth’s crust were created where past salt water oceans and sea life were located where the salt water brine readily dissolved radionuclides and minerals. Many of the naturally-occurring radionuclides in the thorium and uranium decay series, shown in Table I and Table II, are mobile and can be brought to the surface with the oil and gas products, in water, and in the drill cuttings.

TABLE I Radionuclides of the Thorium Decay Series

Thorium-232 Decay Series		
Nuclide	**Half-Life**	**Primary Emission Type**
Th-232	1.4×10^{10} y	α
Ra-228	5.7 y	β
Ac-228	6.1 h	β, γ
Th-228	1.9 y	α, γ
Ra-224	3.7 d	α, γ
Rn-220	55.6 s	α
Po-216	0.15 s	α
Pb-212	10.6 h	β, γ
Bi-212	61 m	α, β, γ
Po-212	3×10^{-7} s	α
Tl-208	3.1 m	β, γ
Pb-208	Stable	none

TABLE II Radionuclides of the Uranium Decay Series

Uranium-238 Decay Series		
Nuclide	**Half-Life**	**Primary Emission Type**
U-238	4.5×10^9 y	α
Th-234	24.0 d	β, γ
Pa-234m	1.2 m	β, γ
U-234	2.5×10^5 y	α, γ
Th-230	7.7×10^4 y	α, γ
Ra-226	1.6×10^3 y	α, γ
Rn-222	3.83 d	α
Po-218	3.1 m	α
Pb-214	27 m	β, γ
Bi-214	20 m	β, γ
Po-214	1.6×10^{-4} s	α, γ
Pb-210	22.3 y	β, γ
Bi-210	5.01 d	β
Po-210	138 d	α
Pb-206	Stable	none

Liquids

From a radioactivity standpoint the progeny of the thorium and uranium series that commonly exist in formation water is of concern. The formation water in the oil and gas deposits contains elements from Group IIA of the Periodic Table, including calcium, strontium, barium, and radium, each dissolved from the reservoir rock [3]. Naturally occurring Ra-228 and Ra-224 (from the thorium decay series) and Ra-226 (from the uranium decay series) are present in the formation water in widely varying concentrations. These nuclides (and their progeny) are brought to the surface during oil and gas activities in the waste fluids. Depending upon the planned treatment or disposal of the extracted fluids, various radioactive wastes may be produced including de-watered sludge, wastewater filter cake, contaminated wastewater treatment equipment, and pipe scale.

Many oil and gas companies have chosen to treat their fluids for safe surface discharge or possible reuse. The wastewater processed by mobile or central treatment facilities typically consists of water mixed with fracking chemicals (e.g. friction reducers, biocides, surfactants, etc.), sand proppant, residual, and naturally occurring contaminants that become integrated with fracking water recovered from wells (e.g. dissolved solids, metals, radioactive materials, and organics). Because of the natural and artificial prevalence of Group IIA elements in the process and flowback water, the wastewater treatment process is intended to remove barium from the wastewater. Radium and barium, both Group IIA elements behave chemically similar. Thus, it is during the barium extraction processes that radium becomes concentrated, depositing in significant quantities as pipe scale and as wastewater filter cake solids. This concentrated material is classified as technologically-enhanced NORM (TENORM). Table III provides the range of concentrations in TENORM-containing wastes for produced water and pipe / tank scale [4]. Varying natural concentrations and chemical processes contribute to the wide ranging levels shown in Table III.

TABLE IIIRadioactivity Levels Found in TENORM-Containing Wastes

Type of Waste	Radioactivity Level	
	Low	High
Produced Water [Bq/liter]	3.70E-03	3.33E+02
Pipe/Tank Scale [Bq/g]	<9.25E-03	3.70E+03
WWTF Ra Sludge [Bq/g]	7.40E-02	1.67E+01

Gases

The radioactive gas and noble element Radon-222 (a decay progeny in the uranium decay series) is present in varying degrees in the oil and gas formations. Because radon is the only gaseous radionuclide in the U-238 decay series, it more readily travels with the gas stream than its non-gaseous parent and progeny radionuclides. In addition to the presence of radioactive radon gas with the natural gas, transportation of the radon-containing natural gas results in a build-up of thin radioactive film layers of the radon progeny that have decayed during transportation. As the Rn-222 progeny decay and change from a gas into a solid, the atoms are deposited on the inner surfaces of natural gas processing and transportation equipment including scrubbers, compressors, valves, and pipelines. The radioactive film is primarily composed of the longer-lived Pb-210 and Po-210 radon progeny. Rn-222, along with most of the decay progeny, have relatively short half-lives in comparison to Pb-210 and Po-210 with half lives of 22.2 years and 138 days respectively [2]. Polonium-210 in natural gas pipelines and pipe filters has been identified and quantified in concentrations as high as 3.7E4Bq/g.

Lead-210 and Po-210 contamination in the natural gas processing and transportation equipment commonly goes unidentified because their radiation emissions require alpha and low-energy beta radiation detection equipment. Unless specific screening measurements are performed with the intent to measure alpha and beta radiation it is likely that Po-210 and Pb-210 will not be immediately identified. The lack of identification of contamination from these two radionuclides presents added worker exposure risk. The radioactive decay of Po-210 is by alpha emission, which requires additional safety protocols for handling of materials with potentially high concentrations.

NORM AND TENORM REGULATIONS

United States

Regulations in the U.S. concerning NORM and TENORM range from almost non-existent in some states to complicated and contradictory in others. On a federal level, the U.S. Nuclear Regulatory Commission (U.S. NRC) does not regulate or license NORM and TENORM, defaulting to the authority of the 50 individual states. Various other federal agencies regulate certain aspects of NORM and TENORM. For example, the U.S. Department of Transportation (U.S. DOT) regulates the packaging, labeling, and transportation of NORM- or TENORM-containing materials, defined in 49CFR173.401, although exemptions in the regulations provide ease in some cases. Another example is the U.S. Environmental Protection Agency (U.S. EPA) who regulates radioactivity in drinking water under 40CFR141-40CFR149, and is currently undertaking a study across the U.S. to better understand the potential impacts on drinking water resources from hydraulic fracturing, the results of which are expected to be released in 2014. The U.S. EPA has also joined a multi-agency collaboration with the U.S. Department of Energy (U.S. DOE) and U.S. Geological Survey (U.S. GS) to develop a research plan to address questions regarding unconventional shale gas and tight oil reserve development.

In the U.S., a state can enter into an agreement with the U.S. NRC or its predecessor agency (the Atomic Energy Commission) allowing a state to have their own radiation protection regulations as long as the state’s regulations are equal to or more stringent than the U.S. NRCs. These self regulating states, thirty seven out of fifty, are known as “Agreement States”. The Agreement States have radiation control programs, radiological materials licensing, and expertise to regulate NORM and TENORM but that does not necessarily mean NORM and TENORM regulations are in place and are being enforced. The remaining thirteen non-agreement states typically have limited radiation control infrastructure, however, in certain cases, NORM and TENORM regulations do exist. Even in the states that have substantial existing regulatory infrastructure, almost the entire radioactive material regulatory framework is not designed for the unwanted NORM and TENORM that impacts the oil and gas industry. In short, each state’s regulations or lack thereof exist in varying levels of maturity with minimal standardization or consistency within and across state lines. In states with no specific NORM / TENORM regulations, worker safety is governed by U.S. Occupational Safety and Health Administration (U.S. OSHA) regulations. This paper will summarize the regulatory status of two Agreement States actively participating in hydraulic fracturing methods for oil and gas production.

The Bakken shale formation, partially located in the State of North Dakota (ND), contains large reservoirs of oil and gas and is an important player in the recent boom in the hydraulic fracking market. The State of ND, an Agreement State, regulates NORM under the same regulations that apply to other radioactive material in the state. NORM is under the regulatory control of the ND Department of Heath except for transportation, in which case the U.S. DOT regulations apply, and depending on the circumstance, additional NORM handling and management activities may be subject to U.S. OSHA regulations. In ND, materials or equipment found to contain less than 1.85E-1Bq/g (5pCi/g) total Ra are not considered NORM and may be disposed of or released for unrestricted use. Material or equipment found to contain more than 1.85E-1Bq/g (5pCi/g) are considered NORM and must be stored, handled, transported, and disposed of in accordance with ND radiological health rules. It is important to note that ND has no facility within the state that can accept material or equipment above 1.85E-1Bq/g (5pCi/g) Ra for disposal. The state of ND has recently expressed interest in opening a licensed disposal facility for radiological waste. Until such a licensed disposal facility is opened, all NORM-containing waste must be shipped out of state for disposal.

Texas (TX) is another state heavily involved with oil and gas production. NORM produced from oil and gas is regulated by the TX Railroad Commission. All other NORM (other than oil and gas) including the possession, use, transfer, transport, and storage of NORM is regulated by the TX Department of State Health Services (TX DSHS). The TX DSHS requires a general license for any person who possesses NORM (other than oil and gas NORM) above exemption criteria defined as 1.11Bq/g (30pCi/g) Ra-226 and Ra-228 or 5.55Bq/g (150pCi/g) for other NORM radionuclides. NORM contaminated equipment is defined as equipment that exhibits a minimum gross radiation exposure level greater than 50uR/hr at any accessible point. Provided certain stipulations are met, authorized disposal methods allowed in the TX Railroad Commission regulations allow disposal of oil and gas NORM by the generator include on site burial, on site landfarming, and disposal between plugs when abandoning wells. Additional NORM disposal is permitted at facilities licensed by the TX DSHS. Additional NORM rules are in draft stages in TX.

Canada

Canada is a country with mature regulations pertaining to NORM and TENORM generated during oil and gas activities. Excluding the import/export and transportation of NORM- and TENORM-containing materials (regulated federally) NORM wastes are regulated provincially. Some inconsistencies between provinces led to the publication in October 2000 of the "Canadian Guidelines for the Management of NORM" [5]. The guideline document was published to help facilitate standardization for management of NORM in Canada and includes detailed procedures and principles for detection, classification, and handling, as well as guidance for compliance with federal transportation regulations [5]. Licenses are required to dispose of NORM or to decontaminate NORM-contaminated equipment and materials. Designated landfills in Canada can accept Ra-containing solids up to 5.0Bq/g and geologic disposal in salt caverns can accept solids up to 70.0Bq/g for permanent disposal. Regulations pertaining to higher concentrations or NORM-containing wastewaters remain non-existent.

DISCUSSION

The oil and gas industry has long relied on the knowledge and expertise of those who manage and control radiological materials particularly during utilization of radioactivity to provide benefit to the industry. As public scrutiny and regulator pressure will continue to increase by bringing NORM and TENORM issues into the spotlight, the industry should again rely on the radiation protection industry experts. Published guidance documents have been issued to provide the framework to address NORM and TENORM concerns associated with oil and gas activities. Basic radiation safety practices can be planned for and implemented long before encountering NORM to control and reduce occupational and public exposures. Proper management of NORM and TENORM, beginning as soon as the material is dislodged from its natural setting in the rock or formation water in the earth, will significantly reduce long-term costs, health risks, and environmental liabilities. Providing proper radiation awareness training needs to become a top priority to educate and increase worker awareness to help facilitate a safe working environment.

Regulatory agencies, both in the domestic and international communities, need to become proactive in facilitating communication and information sharing pertaining to the NORM and TENORM issues affecting the oil and gas industry and environment. Many agencies possess in-house expertise or can consult with radiation experts to develop a better understanding of the issues. In 2013, the State of Pennsylvania initiated a study to examine the levels of naturally occurring radiation in equipment, materials, and media associated with oil and gas development in an effort to understand the potential for health and environmental impacts. The study will be the most extensive and comprehensive study ever done [6] which can provide significant information to other states in the U.S. and to the international community as a whole.

CONCLUSION

The recent boom in hydraulic fracturing for oil and gas has put radiological issues into the spotlight. Naturally-occurring radioactivity is brought to the surface as solids, liquids, and gases. Vertical and horizontal drill cuttings (solids) contain radionuclides of the uranium and thorium decay series. The process and flowback water (liquids) brought to the surface contain Ra-224, Ra-226, and Ra-228 along with their decay progeny which may ultimately concentrate during wastewater treatment processes. Natural gas contains Rn-222 (gases) and its decay progeny that potentially deposit themselves in a thin radioactive layer in natural gas equipment and transportation materials.

Oil and gas companies should be proactive to properly manage NORM and TENORM regardless of the regulatory status in a state, providence, or country. Utilizing radiological expertise to provide appropriate awareness training and radiation protection practices will ultimately reduce long-term costs, health risks, and environmental liabilities.

Additional disposal facilities are a necessity in the international community as NORM and TENORM awareness continues to grow. The regulatory agencies must continue to evolve with the oil and gas industry to help facilitate safe practices and to ensure proper disposal of material. Continued cooperation between industry experts, health physicists, regulators, and the public will facilitate reasonable and effective regulations are passed (if necessary) that are protective of the environment and worker safety and health, while allowing the industry to continue to expand in a safe and profitable manner.

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