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REPORT

A HOT FRACKING MESS:

HOW WEAK REGULATION OF OIL AND GAS PRODUCTION LEADS TO RADIOACTIVE WASTE IN OUR WATER, AIR, AND COMMUNITIES

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Executive Summary

Oil and gas extraction activities, including fracking, drilling, and production, can release radioactive materials that endanger workers, nearby communities, and the environment. The United States has known about these dangers for at least 30 years, ever since an EPA report revealed the health risks of unregulated radioactive oil and gas waste. Since then, additional research has confirmed those findings. Yet, even as oil and gas exploration and production have boomed across the United States, the country continues to lack any federal regulations governing the handling and disposal of radioactive waste and materials generated from these activities, leaving Americans reliant on spotty and loophole-ridden state oversight.

Every stage of oil and gas production can produce what is known as "technologically enhanced naturally occurring radioactive material," or TENORM. During drilling, radioactive elements are carried to the surface via used drilling fluids and drill cuttings. During fracking, radioactive elements mix with flowback fluid. And radioactive elements are often present in the massive volumes of wastewater produced by a working oil or gas well. The U.S. oil and gas industry produced an estimated one trillion gallons of this dangerous wastewater in 2017 alone.

Radioactive materials not only can contaminate oil and gas compressors, pumps, pipes, and storage facilities, creating a hazardous environment for workers, but also can enter the environment through the mismanagement of oil and gas waste. Waste can leak out of storage pits, tanks, and landfills or spill during transportation. It is sometimes purposely spread over land and mixed with the soil in an industrial waste management practice known as "land farming." Wastewater may be used for dust suppression or deicing roads. These practices deliberately introduce millions of gallons of oil and gas wastewater into the environment every year. In fact, a recent report from the National Council on Radiation Protection and Measurements concluded that the amount of oil- and gas-generated TENORM released into the environment has increased.

If this TENORM is not adequately managed and disposed of, it poses significant health threats to oil and gas workers and their families and nearby residents, primarily increasing the risk of cancer. Making the situation even more dangerous, many oil and gas activities take place in residential neighborhoods, in close proximity to homes, schools, and playgrounds.

Despite the clear health risks, there are no dedicated federal regulations to ensure comprehensive and safe management of radioactive oil and gas materials. More general regulations that might apply have loopholes that render them meaningless. States have addressed some federal regulatory gaps, but overall, state regulations are inadequate to protect human health and the environment. For example, a review of regulations in 12 major oil- and gas-producing states found that 4 of the 12 have no standards for the level of radioactive material in oil and gas waste that can be accepted at landfills, only 3 require monitoring of radioactive material in the wastewater that leaches out of landfills, and 10 allow oil and gas wastewater to be spread on roads for uses such as dust suppression or deicing.

Compounding the problem, radioactive oil and gas wastes are frequently transported across state lines as waste haulers take advantage of the lack of consistent state TENORM regulations to search for the cheapest or easiest way to dispose of radioactive material. This means that waste is transported through more communities over longer distances than necessary, increasing the risks of leaks or spills.

For this report, NRDC reviewed TENORM in the oil and gas industry, how it is released into the environment, and how it is regulated (if at all) at the federal and state levels. Case studies in Kentucky, North Dakota, Ohio, Pennsylvania, and Wyoming were used to further illuminate the situation. On the basis of this review, NRDC recommends the following steps to protect communities and the environment from the dangers of TENORM produced by the oil and gas industry:

- Congress must close the gaps in our federal laws that allow oil and gas companies to avoid complying with radiation safeguards that apply to other industries.
- States should have comprehensive, effective regulations governing the activities of any industry that generates radioactive material, including the oil and gas industry. State regulations should include standards for worker and site safety; reuse of site equipment and materials; waste management, transfer, and disposal; monitoring of surface, groundwater, and air emissions and other environmental monitoring; adequate levels of financial assurances; and abandoned wells.
- Worker protections must include adequate initial and refresher training on radiation safety and regulations for every stage of the exploration and production process, including calibration and use of radiation detection instrumentation, use of protective clothing to reduce the risk of transferring contamination, suitable respiratory equipment to prevent inhalation of airborne radioactive contaminants, and robust confinement of radioactive materials to prevent release into the environment.

For decades, failure to adequately regulate TENORM has allowed the oil and gas industry to produce large quantities of potentially dangerous radioactive material and indiscriminately release it into the environment—putting public health and the environment at risk. Federal and state regulations must ensure that this waste is safely managed, stored, transported, and disposed of.

Introduction

Radioactive elements are naturally present in many soils and rock formations, as well as in the water that flows through them. Oil and gas exploration and production (E&P) activities can expose significant quantities of this radioactive material to the environment.[1] Drilling an oil or gas well brings used drilling fluids and drill cuttings to the surface. Fracking, which uses water, chemicals, and proppant such as sand, used to keep fractures open, to bore through underground rock, creates flowback fluid that comes up to the surface and needs to be disposed of.

There are several differences between conventional wells and fracked wells. The former are located in highly permeable formations where oil and gas flow out easily, while fracking takes place in "unconventional" oil and gas wells, meaning they are in low-permeability formations, also called tight formations. Also, conventional wells are drilled only vertically, while unconventional wells, such as those in shale or tight sandstone, may be drilled vertically or horizontally. Unconventional wells may generate greater volumes of waste, but both types generate waste that can contain high levels of radioactive material.[2]

Throughout the oil and gas development process, radioactive material can enter the environment both accidentally and intentionally. During production, equipment such as compressors, pumps, and pipes may be exposed to radioactive material. The waste management process also presents many opportunities for radiation to be accidentally released, such as in spillage or leakage of waste in transit or from the pits, tanks, or landfills where it is stored. Additionally, wastewater and equipment may be brought to facilities to be processed for reuse, sometimes in other drilling or fracking operations. There are also so-called beneficial reuse methods that intentionally reintroduce radioactive material into the environment, such as road spreading, where wastewater is sprayed directly onto roads for dust suppression or deicing. Another form of intentional reintroduction is the use of so-called land farming, a waste-management approach in which industrial waste, such as oil and gas drill cuttings, is mixed with microbes that help break down contaminants and then mixed with soil.

A drilling rig as seen from the playground of nearby Summit Elementary School in Butler, Pennsylvania.

The radioactive material unearthed during oil and gas E&P is known as "naturally occurring radioactive material," or NORM. When it has been concentrated or exposed to the environment by industrial activity, it's called "technologically enhanced" NORM, or TENORM. The fact that the oil and gas industry produces TENORM isn't a new problem; it was documented in a 1987 U.S. Environmental Protection Agency (EPA) report to Congress, *The Management of Wastes From the Exploration, Development, and Production of Crude Oil, Natural Gas, and Geothermal Energy*. In that report, the EPA revealed that radioactive materials, such as cancer-causing radium, had been found in wastewater from the oil and gas industry. Its analysis detected radium-226 in wastewater at levels up to 395 picocuries per liter (pCi/l) and radium-228 at levels up to 570 pCi/l.[3] The EPA's maximum contaminant level standard for combined radium-226 and radium-228 in drinking water is only 5 picocuries/liter.[4]

On December 3, 1990, the front page of *The New York Times* declared, "Radiation Danger Found in Oilfields Across the Nation."[5] The newspaper reported that there were no federal regulations dealing with "oilfield radiation," despite the fact that "radium has been found in every oil-producing region in the country, from Alaska to Florida." It detailed incidents in which old, contaminated oilfield pipes were used in playground equipment and to train welding students. A lawsuit had even been filed against Chevron and Shell for not warning workers at a pipe-cleaning yard about the radiation levels in used pipes.[6]

But awareness has not led to action. In 2018, the Association of State and Territorial Solid Waste Management Officials reported that "the oil and gas production industries are historically known as the major generators of TENORM waste" and that "it is expected that the volumes of high activity TENORM waste generated will increase in the future."[7] Yet the organization concluded that such wastes continue to be generally unregulated and that, due to the lack of either federal or state regulations for many radioactive materials, generators are often not required to dispose of this material in a specific manner.

In the 30 years since the 1990 *New York Times* article, oil and gas E&P in the United States has seen massive growth, only increasing the amount of dangerous TENORM produced by the industry. From 1990 to 2019, the volume of crude oil produced in this country increased by 67 percent, and natural gas production increased by 90 percent.[8] At the end of 2018, the United States was home to approximately one million active oil and gas wells—all generating waste.[9] The domestic oil and gas industry created an estimated one trillion gallons of produced water, wastewater generated during production, in 2017 alone.[10]

Yet there are still no specific federal regulations to ensure comprehensive and safe management of radioactive oil and gas materials, including waste. To the contrary, the federal regulatory structure pertaining to radiation risk in the oil and gas industry continues to be riddled with loopholes. Some states have established rules to address gaps in federal regulations, but no state has adequately protected health and the environment from this dangerous material (Appendix A).

Research has found that radioactive materials present significant health risks, including the risk of lung cancer and other forms of cancer. Despite this danger, many oil and gas activities take place in residential neighborhoods, near homes, schools, and playgrounds.[11] In some cases the impacted environment can never be restored to its previous condition.[12] Moreover, oil and gas waste with known radioactive material is frequently transported across state lines throughout the United States as waste haulers search for the cheapest or easiest way to dispose of this dangerous material, putting countless additional communities at risk of exposure.[13] And then there are risks to the workers themselves. Research has found that these radioactive materials "pose significant risks to a large number of people involved in the oil and gas industry."[14]

We cannot continue to ignore this threat and sweep these dangers under the rug. Congress must close federal regulatory gaps and introduce real safety standards for the disposal and handling of radioactive gas and oil waste.

THE TROUBLE WITH DEFINING NORM AND TENORM

NORM and TENORM are defined differently by different parties, including federal and state regulators. In this report we use the definitions of the EPA."[15]

The EPA defines NORM as "materials which may contain any of the primordial radionuclides or radioactive elements as they occur in nature, such as radium, uranium, thorium, potassium, and their radioactive decay products, such as radium and radon, that are undisturbed as a result of human activities." And it defines TENORM as "naturally occurring radioactive materials that have been concentrated or exposed to the accessible environment as a result of human activities such as manufacturing, mineral extraction, or water processing."

Some states use a narrower definition of TENORM than the EPA does, one that considers increased concentration but not the potential for human exposure to radioactive materials. This difference in definitions makes effective TENORM regulation challenging. In addition, the EPA definition is given only as "guidance," a government directive that is not enforceable in the same way as regulations.

Radiation From Oil and Gas Waste Threatens Human Health

Exposure to radium-226 and radium-228, both present in many forms of oil and gas waste, can cause cancer.[16] Studies from the early 1900s indicate that chronic exposure to radium can induce bone sarcomas, cancers that originate in bones and connective tissue. Radium also decays into radon isotopes, which can attach themselves to dust and, when inhaled, deposit radiation in lungs and cause lung cancer. In fact, radon is the second-leading cause of lung cancer in the United States.[17] Radon decay products, including lead-210 and polonium-210, are also present in high levels in gas handling equipment and can further contribute to cancer risk.[18] Scientists are also currently investigating the potential non-cancer health effects of radioactive particles.[19]

Radioactive elements naturally exist in the environment around us, at low and generally unharmful levels. These elements, which include cosmic radiation from the sun and stars, terrestrial radiation from the earth, and internal radiation that exists in all living things, are often referred to as natural background radiation, which is another name for NORM.[20] Most NORM, and even most TENORM, contains only trace amounts of radioactivity and are part of our everyday landscape.

Underground oil and gas reservoirs, however, often contain elevated levels of NORM in comparison with that found aboveground, mostly in the uranium-238 and thorium-232 natural decay series.[21] In fact, high concentrations of radium and radon—which are produced by uranium and thorium—can act as an environmental marker of oil- and gas-rich reserves and are often used to guide drilling operations.

Once drilling begins, NORM that would have otherwise been confined beneath the surface of the earth can be released into the air, onto land, or into surface water or groundwater and can become concentrated, lead to environmental contamination, and accumulate in people's bodies.[22] Recent research that analyzed air samples downwind from more than 150,000 unconventional oil and gas wells across the country found elevated levels of airborne radioactive particles that could induce adverse health effects in nearby residents.[23] Scientists have also found statistically significant correlations between radon levels inside homes and proximity to fracked shale gas wells in Ohio and Pennsylvania.[24]

An aerial view of a frack pad site in Jefferson County, Ohio, in November 2020.

As mentioned above, TENORM produced by oil and gas E&P may contain a wide variety of radioactive materials. The health dangers they pose depend entirely on exposure levels.[25] If properly disposed of, oil and gas waste can pose little risk to the general public or workers. For example, modeling by Argonne National Laboratory found that workers exposed to average TENORM concentrations using personal protective equipment (PPE) would likely receive an annual dose less than the recommended limit of 100 millirem per year.[26] However, equipment-cleaning workers exposed to potential maximum radionuclide concentrations of TENORM from the waste stream—as is possible under current regulations—could receive an annual dose higher than 100 millirem per year even if PPE is properly used.

The oil and gas industry has known about the health risks to those working with radioactive materials in oil and gas waste since the 1980s.[27] Workers (or their survivors) have sued oil and gas companies under state tort law, alleging that through jobs such as pipe cleaning, pipe maintenance, and yard maintenance, they were unknowingly exposed to radioactive oil field waste materials that resulted in, caused, or contributed to the development of various illnesses and deaths.[28]

In expert testimony submitted in one lawsuit, scientists assessed the radiation exposures of 33 oil and gas workers. Of the 33 plaintiffs, 31 were diagnosed with cancer and two were diagnosed with diseases that often precede a cancer diagnosis. The experts concluded that the workers were regularly exposed to radioactive material without proper protection and that the diagnosis in each case was "a consequence of their occupational exposures to radiation."[29]

Moreover, improper disposal of oil and gas E&P waste can spread exposure far beyond an oil and gas site.[30] Without proper regulation of this waste, unsafe management and disposal practices will persist, workers will continue to be exposed to radiation, and Americans across the country will continue to face health risks from unregulated radioactive material.

GLOSSARY OF RADIOLOGICAL TERMS

Radiological terms can sound similar but mean different things.

Radioactive material or radionuclide: Material that emits radiation.

Radiation: Energy that is released from atoms during radioactivity in the form of subatomic particles or photons. It travels through the air and can penetrate certain materials. Radiation can lead to changes in living cells and is potentially harmful if not managed correctly.

Radioactivity: A process by which the nuclei of unstable atoms spontaneously transform into the nuclei of more stable elements—also known as radioactive decay.[31]

NORTH DAKOTA: DUMPING OF RADIOACTIVE FILTER SOCKS

In 2014, federal and state officials in North Dakota found radioactive "filter socks" that had been illegally dumped at sites around the state. Filter socks, shaped like large tube socks, are used during wastewater treatment to strain out solids, such as fracking proppant. Investigators found thousands of pounds of these filter socks in leaking trailers outside Watford City.[32] At another site, in the town of Noonan, county officials found hundreds of plastic bags stuffed with used radioactive filter socks filling six rooms of an abandoned gas station.[33] State officials estimated that the North Dakota oil and gas industry generated as much as 70 tons of used filter socks each day, and these could contain large amounts of radioactive material.[34]

The North Dakota Health Department published new TENORM rules in 2016 that changed landfill regulations to deter illegal dumping, limit the amount of waste that a facility can accept each year, and set standards for the depth of underground burial.[35] Additionally, the North Dakota Industrial Commission now requires oil and gas operators using filters or filter socks to have a leakproof covered container on each well pad and at each Underground Injection Control disposal well site to store the filters and socks until they are transported off-site.[36] These are steps forward but are not sufficient to provide the levels of protection that are needed.

Unfortunately, concerns about radioactive contamination in North Dakota are not limited to filter socks; samples taken at oil and gas wastewater spill sites in the Bakken region detected elevated total radium in soil and water.[37] And these new rules might just export the problem to other states. For example, a landfill near the Columbia River in Oregon accepted two million pounds of radioactive fracking waste from North Dakota from 2016 to 2019—in violation of Oregon state rules.[38]

Used filter socks among other debris at a fracking site in North Dakota.

Federal Regulatory Gaps Result in Improper Disposal of Radioactive Materials

As mentioned above, the risks of oil and gas waste extend far beyond workers and into surrounding communities. The Conference of Radiation Control Program Directors, an association of state and local radiation control professionals, has concluded that "no federal regulations explicitly govern the management and disposal of TENORM associated with the oil and gas industry."[39] Unfortunately, without adequate regulations, there is scant industry monitoring data or information about violations, so the full scope of health impacts facing nearby residents or workers from TENORM exposure remains unclear.

The best federal guidance we have is nonbinding, issued by the EPA in 2003, which recommends taking three steps if a site is suspected of having radioactive materials above background levels resulting from human activities:

1. EPA staff should be contacted to help determine next steps for site surveys, field sampling, and monitoring.
2. Worker exposure should be avoided.
3. Cleanup, waste management, and post-closure decisions should take into account radioactive contamination.[40]

While this should technically apply to TENORM at oil and gas production sites, there is no evidence that this process has ever been followed in the oil and gas industry. At the same time, our bedrock federal environmental, health, and safety laws have gaping loopholes and exemptions that allow radioactive oil and gas materials to go virtually unregulated. States have instituted some of their own policies, but they vary greatly.[41] Below, we discuss the gaps in key federal laws and the resulting inadequate regulatory scheme.

RADIATION IN WASTE PRODUCED BY OIL AND GAS E&P

Oil and gas E&P produces massive amounts of waste, which can contain radioactive materials and man-made chemical additives. Techniques used in the industry for storing, handling, or disposing of waste include storage in open-air pits, evaporation into the air, removal to landfills, underground injection, flaring, so-called land farming (spreading over land and mixing with soil to encourage breakdown by microbes), discharge into rivers or streams, reuse of wastewater in drilling or fracking, recycling of wastewater for deicing or suppressing dust on roads, agricultural uses, or recycling of metal materials like used pipe into other metal products. It may be transported by pipeline, rail, barge, or truck.[42]

These are the most common kinds of waste:

Drill cuttings (bit cuttings): Underground rock and associated material brought to the surface by drilling. The volume of drill cuttings produced from each well is primarily a function of the depth and length of the well and the diameter of the well bore.[43] When drilling a well, a large proportion of cuttings come from higher-radioactivity oil and gas formations.[44] The EPA estimated that 33.5 million barrels of drill cuttings weighing 7.5 million tons were generated nationwide in 2016 alone, although the agency acknowledged that this "may underestimate waste volumes to some degree."[45] These drill cuttings may be taken to a landfill, buried on a well pad, disposed of via land farming, or dealt with in other ways.

Flowback: Mix of gases and fluids that return to the surface after fracking, a process that uses hydraulic fracturing fluids and proppant to blast through an oil and gas well and into the targeted formation at high pressure. Proppant is sand or similar material, sometimes coated with chemicals, that props open the fractures created by the fracking process. Fracking releases radium from the formation into the flowback, and therefore flowback can contain elevated radioactive elements.[46] Flowback is collected at the surface and often injected underground into a disposal well. Alternatively, it may be recycled for use in other fracking operations, a growing practice that may result in fluids becoming more radioactive with each progressive use.[47]

Wastewater (produced water, brine, production water): Once a well is put into production, it generates not only oil and gas but also wastewater that is brought to the surface throughout a well's productive life, which can last for decades. It is collected on site and then disposed of on-site or transported off-site for disposal or reuse.[48] This so-called produced water typically has a high concentration of TENORM as well as total dissolved solids, salt, and potentially other contaminants such as heavy metals, hydrocarbons, and volatile organic compounds, all of which can be very harmful to groundwater, surface water, or soil.[49]

Contaminated equipment (pipes, filter socks, pit liners, etc.): Equipment that is exposed to radioactive materials over time.

RADIATION IN WASTE PRODUCED BY OIL AND GAS E&P Continued

A cross-section of a heat exchanger tube with a thick layer of limescale build-up on the inner wall.

Scale: A mineral deposit that can accumulate on the inside of pipes and casings used in oil and gas wells. Scale in enough quantities can restrict or stop the flow of oil or gas, so the removal of scale is a common and necessary practice in the oil and gas industry, and it exposes workers to any radioactivity present in the scale. Depending on state regulations, scale may be disposed of at a landfill, buried on-site, injected underground into a disposal well, or handled in other ways. The use of scale inhibitors in unconventional oil and gas production has led to lower accumulations of scale, but this only transfers the problem to other media (e.g., produced water).[50]

Sludge: Sludge is the mix of oil or other liquid hydrocarbons, dirt or sand, sediment, and residue that's left on the bottoms of storage tanks. Although the concentration of radiation is lower in sludges than in scales, sludges are more soluble and, therefore, more readily released to the environment. As a result, they pose a higher risk of exposure to maintenance workers from fumes and radon in confined spaces. Sludge may be disposed of in an underground injection well, spread on land, or disposed of on-site.

Residual treatment waste: The oil and gas industry sometimes processes, treats, or recycles its waste in order to reuse of some of the materials.[51] However, treatment can result in more concentrated radioactive waste. When wastewater is treated, for example, the solids are filtered out and dried; they then may be packed into bricks or cakes before being transported elsewhere for disposal. These cakes are extremely concentrated wastes. The treatment facilities that produce them have been called "enrichment factories for the radioactive element."[52]

Pigging wastes: Scale and sludge generated when the interiors of pipelines are cleaned of residue by equipment known as pigging devices. These wastes can contain dangerous levels of radioactive material.[53]

THE RCRA GAP

The Resource Conservation and Recovery Act (RCRA) was enacted in 1976 to establish comprehensive national standards for waste management.[54] Subtitle C of RCRA contains requirements for "hazardous waste"—waste that can cause or significantly contribute to an increase in mortality or serious irreversible illness or can otherwise pose a substantial hazard to human health or the environment when improperly treated, stored, transported, disposed of, or otherwise managed.[55] In 1980, Congress amended RCRA to temporarily exempt most wastes associated with oil and gas E&P from these hazardous waste regulations, pending the completion of an EPA study.[56]

The EPA completed the study in 1988. It found that E&P wastes contain toxic substances— some of them at high levels—that endanger both human health and the environment. Uranium, for instance, was detected at "levels that exceed 100 times EPA's health-based standards."[57] Nevertheless, the agency issued a determination that federal regulation of E&P wastes under Subtitle C, including any radioactive waste, was unwarranted.[58] An EPA employee at the time said that this decision was based on "solely political reasons" and that "politics overrode science."[59] The decision continues to stand today. No E&P waste is subject to federal hazardous waste regulations, regardless of how toxic it may be.

Subtitle D of RCRA regulates "solid wastes," generally waste that is not hazardous.[60] Even if oil and gas wastes are not subject to Subtitle C for hazardous waste, they should be regulated under Subtitle D. However, there are no specific solid waste regulations for oil and gas wastes. In 2016, NRDC and partner organizations filed a federal lawsuit against the EPA, calling for the agency to revise the RCRA Subtitle D regulations and stop oil and gas companies from handling and disposing of drilling and fracking wastes in ways that threaten public health and the environment.[61] EPA concluded that no revisions to its regulations were necessary.[62]

Closing the oil and gas gaps in Subtitles C and D would be a big step forward, but that would not be enough to ensure safer management of E&P radioactive waste, because the EPA's current definition of toxicity does not cover radioactive material. RCRA (and the corresponding exemption in the Atomic Energy Act; see below) needs to be changed to include radioactivity in its criteria for what makes a material hazardous.

While the EPA has stated that it expected state regulators to fill the gaps left by its decisions to exempt oil and gas E&P wastes from RCRA regulations, these decisions have only resulted in a patchwork of regulations nationwide that is not adequate to protect public health and the environment.

An aerial view of frack ponds.

THE ATOMIC ENERGY ACT GAP

The Atomic Energy Act (AEA), passed in 1946 amid post–World War II national security concerns, is considered the foundational U.S. law regulating radioactive materials. It sets standards for their possession, development, use, disposal, and decommissioning.[63] The AEA is concerned with the fission process and nuclear fuel used at nuclear power plants as well as certain other defined types of radioactive materials—including low-level waste, source material, special nuclear material, and their by-products. The statute, however, does not cover all radioactive materials. It ignores NORM entirely and does not capture most TENORM, including that produced by the oil and gas industry.

The Nuclear Regulatory Commission (NRC) has issued regulations to implement the AEA, but these regulations consider only two forms of TENORM to be source material—uranium and thorium—and exempts "unimportant quantities" of these two elements from regulation. Anything under 0.05 percent of weight is considered an unimportant quantity, thereby exempting typical oil and gas waste even though it is known that small amounts can accumulate dangerously over time.[64]

THE TRUCKING GAP

Oil and gas waste is often transported to treatment facilities or to disposal sites such as landfills and injection well sites. This transport may take place by truck, barge, or rail. The NRC and the U.S. Department of Transportation (DOT) co-regulate the transport of radioactive material.[65] These agencies have established rules to maintain safe transport and management of radioactive material and to reduce exposure in case of an accident. However, because radioactive waste from E&P is not regulated by the NRC or under RCRA's protective requirements for transporters, it is exempt from key NRC rules for the transportation of hazardous material that apply to other industries.[66]

TENORM generated by oil and gas drilling and fracking processes is subject to the DOT's Hazardous Materials Regulations, but only if the concentration of radioactive materials in the oil and gas waste exceeds regulatory thresholds.[67] These thresholds are high; they were designed to protect people exposed to an accidental large release of radioactive material. They were not designed to protect truck drivers or others who work in close contact with lower-level radioactive materials on a frequent basis, such as happens in oil and gas production.

One truck driver in the Marcellus region reported having hauled produced water for years without receiving from his employer any information on its potential radioactivity or proper protective equipment to shield him from exposure to radioactive material. Concerned, he brought 11 samples of the wastewater in his truck to the Center for Environmental Research and Education at Duquesne University. Testing found four samples that had combined radium levels above 3,500 pCi/l, and one over 8,500 pCi/l.[68] Yet oil and gas industry truck drivers are not considered radiation workers under the law, and there are no limits or regulations regarding their exposure to radioactive wastewater. This exposure can be potentially dangerous if drivers are not trained as radiation workers and properly protected.

WYOMING: UNSAFE WASTEWATER DISPOSAL

Scientists studied sediments from six sites in Wyoming where oil and gas operators were permitted to discharge their wastewater into streams. Their analyses found radium levels ranging from 5.4 to 97.2 picocuries per gram (pCi/g).[69] At one site, they found elevated radium levels more than 30 kilometers downstream of where the wastewater was discharged, in sediment as deep as 30 centimeters. These levels are dangerous, exceeding the standard of 5 pCi/g of total radium established by the EPA as a protective health-based level for contamination cleanup.[70] The researchers estimated that only 5 percent of the total annual radium discharge is retained in stream sediments within 100 meters of the discharges; the rest is transported farther downstream. This is a troubling indication of how far TENORM radiation released at a specific site can travel into the surrounding community and environment.

THE OSHA GAP

The Occupational Safety and Health Administration (OSHA) sets and enforces standards to ensure safe and healthy working conditions in most states, while some states operate their own OSHA-approved program. OSHA has set standards for protecting workers from ionizing radiation—the type generated by NORM or TENORM.[71] However, these standards are based on scientists' understanding of radiation from the 1970s and are not consistent with updated radiation protection regulations issued by other federal agencies (e.g., NRC and the U.S. Department of Energy).[72] In 2005, OSHA began a fact-finding process on occupational exposure to ionizing radiation and requested input from the public to help it determine if its standards need to be updated, but the agency has yet to revise its outdated rules.[73]

THE CLEAN WATER ACT GAP

The oil and gas industry produces massive amounts of wastewater each year. An estimated one trillion gallons were generated in the United States in 2017 alone, including tens of billions of gallons from offshore wells.[74] Offshore, close to all, if not all, produced water is discharged into the ocean after some treatment. The majority of onshore produced water is injected underground, but some is regularly discharged into surface waters, such as rivers and streams. In 2017, an estimated 5.5 percent of onshore wastewater, or 55 billion gallons, ended up in U.S. surface waters.

The Clean Water Act is the federal law that protects the integrity of our surface waters, both onshore and offshore, and restricts water pollution.[75] Yet this law allows significant amounts of oil and gas wastes to be discharged to surface waters, and the limits on pollutants are not adequate to fully protect human health. In federal offshore waters (more than 3 nautical miles offshore), federal water quality standards do not limit elements of NORM or TENORM. In addition to produced water, they also allow other wastes, including some drill cuttings and water-based drilling fluids, to be discharged into the ocean.[76]

Onshore, or in state-managed territorial waters, some states have water quality standards that differ from the federal standards and may allow discharges into oceans, rivers, or streams without any standards for NORM or TENORM. Produced water from conventional oil and gas wells may also be sent to a publicly owned water treatment facility or a centralized wastewater treatment plant before being discharged into surface waters, but the treatment at these facilities may not remove NORM or TENORM.[77]

PENNSYLVANIA: DANGEROUS WASTE DISPOSAL PRACTICES

In recent years, scientists have found high levels of radioactive material linked to oil and gas waste in Pennsylvania waterways. One study examined sediment from two locations in Conemaugh River Lake; one sample site was 6 miles downstream from a centralized waste treatment plant that accepts oil and gas wastewater, and the second site was 12 miles downstream from a different plant. The scientists found strontium and radium that matched the geochemical signatures of oil and gas wastewater.[78] The lake is used for recreation, including fishing and swimming.

Another study found high levels of radium-226 and radium-228 in sediment from the Allegheny River, Blacklick Creek, and McKee Run, downstream from centralized waste treatment facilities that accept oil and gas E&P waste.[79] These radium levels were up to 650 times the levels in the water upstream of the treatment plants. Pennsylvania had formally asked companies to stop disposing of oil and gas wastewater from unconventional formations in these wastewater treatment plants in 2011, but disposal of wastewater from conventional operations continues to be allowed.[80] Researchers were able to date the radium found in this study to a time after 2011, making it clear that the limited restrictions on wastewater disposal are not enough to protect Pennsylvanians' health.[81]

In another case, fluid leaching out of a landfill that accepts oil and gas waste, known as leachate, was being sent to a wastewater treatment plant that was not able to filter out all the radioactive material. The wastewater treatment plant was discharging water that exceeded the safe drinking water standard for radioactive material into the Monongahela River, less than a mile upriver from a community drinking water source.[82]

Pennsylvania also allows oil and gas wastewater to be spread on roads, mostly in the summer months for dust suppression on dirt or gravel roads in the western part of the state. An average of more than 130 million liters were spread on Pennsylvania roads each year from 2008 to 2014. Scientists tested wastewater in tanks used for road spreading and found a median radioactivity level of 1,230 pCi/l, well above the federal standard for safe drinking water of 5 pCi/l.[83] They simulated rainfall on roads treated with oil and gas wastewater and found that about half of the radium in the wastewater was carried by rain off the road.

THE SAFE DRINKING WATER ACT GAP

The Safe Drinking Water Act (SDWA) was enacted to protect drinking water sources from both naturally occurring and man-made contaminants.[84] Within the SDWA, the Underground Injection Control (UIC) program protects current and future underground sources of drinking water from the underground injection of hazardous and nonhazardous materials, including wastewater.[85] The program established standards for six classes of injection or disposal wells, each intended to handle different types of material. Class I and Class IV wells are the most tightly regulated, since they are designed for the injection of hazardous wastes and radioactive wastes, respectively.

Oil and gas waste, however, is permitted into Class II wells, which have weaker standards than either Class I or Class IV wells. Because of the exceptions in RCRA's hazardous waste provisions and the Atomic Energy Act, described above, oil and gas waste can be injected into these less protective Class II wells for permanent disposal regardless of its characteristics, increasing the risk of contaminating underground sources of drinking water. And the oil and gas industry takes advantage of this loophole, injecting massive amounts of waste, including fracking flowback, underground.

While the injection of wastewater into waste disposal wells is at least covered by SDWA's weaker UIC Class II regulations, the actual act of fracking, which not only injects fluids underground but also blasts apart underground formations to disperse them, is not covered by the UIC program. In 2005, Congress exempted fracking from regulation under this critical program, unless diesel is used in the fracking fluid, even though fracking itself can potentially release contaminants like radioactive material into drinking water sources.[86]

THE CLEAN AIR ACT GAP

The Clean Air Act (CAA) was enacted to control air pollution and promote clean air quality. Within the CAA, the National Emission Standards for Hazardous Air Pollutants (NESHAP) establish limits on the discharge of 187 hazardous air pollutants (HAPs) known to be toxic, including radioactive materials such as radon.[87] Such limits apply either to individual emitting sources or, for most industries, to multiple aggregated small sources of toxic air pollution that are under common control and grouped together in close proximity to perform similar functions. In 1990, however, Congress exempted oil and gas wells and associated pump and compressor stations from the limits on aggregated emissions from smaller sources.[88] Congress allowed EPA the option of regulating individual small E&P facilities like wells and pits if they are within a metropolitan area with a population greater than one million, but the EPA has never done so, even though thousands of these wells exist in metropolitan areas such as Los Angeles, Pittsburgh, Houston, and Denver.[89]

FEDERAL GAPS MUST BE CLOSED

For decades the oil and gas industry has exploited gaps in essential federal environmental laws and polluted clean air, clean water, and other important natural resources in ways that other industries have not. Our failure to regulate NORM and TENORM has allowed the oil and gas industry to generate significant amounts of potentially dangerous radioactive material that is not safely managed, stored, transported, or disposed of. We must do better to protect human health and the environment.

KENTUCKY: RADIOACTIVE OIL AND GAS WASTE

In 1988, used pipes from the Martha Oil Field operated by Ashland Oil, Inc., near the hamlet of Martha, Kentucky, triggered a radiation detector at a local junkyard.[90] This kicked off decades of health concerns in the community, investigations, cleanup efforts, and lawsuits. Radioactive waste including sludge and wastewater had been released throughout the area, including on private property. Waste pits had not been lined, and oil field wastewater had even been disposed of in a local creek.[91]

In the 1990s, scientists investigated a working farm with cattle and crops in the Martha area, finding tanks containing sediment, waste pits with sludge, and abandoned metal pipes. Detecting high concentrations of TENORM in soil and water samples from the farm, they concluded that "the soil and pipe will remain radioactive for many thousands of years" and that future farmers or residents will likely be exposed.[92]

An expert study issued in 2008 analyzed soil and drinking water samples from homes in the community. Out of 29 water samples, 10 had elevated levels of radionuclides, and out of 28 soil samples, 19 were similarly tainted. On the basis of their research, the experts concluded that the elevated levels of radium-226 and radium-228 in well water "[arose] from oil field operations." Although most homes in the study had stopped using their well water in the 1980s, the scientists found that the lifetime exposure of some residents to the oil field radioactive materials "increase[d] the likelihood that cancer and non-cancer diseases may occur."[93]

In the Absence of Federal Regulations, States Have Not Stepped Up

Federal agencies left room for states to fill in some of these regulatory gaps and manage radioactive oil and gas waste within their borders. Unfortunately, state regulations are largely inadequate as well, leaving TENORM often unregulated. Additionally, because these directives are often extremely technical and may be issued by multiple state agencies (e.g., health, environment, or natural resources departments or dedicated oil and gas commissions), it can be difficult for all stakeholders to fully comprehend what regulations do exist.[94]

This is concerning even in states without oil and gas production because waste that contains radioactive material is regularly transported across state lines. For example, in 2016 residents of Irvine, Kentucky, learned that a local landfill had been illegally accepting radioactive fracking wastes from treatment facilities in neighboring West Virginia and Ohio, including filter socks and residual wastes, in violation of an agreement with the community. This landfill is located within a few hundred feet of the local middle and high schools.[95]

NRDC and Fair Shake Environmental Legal Services conducted an analysis of the regulations for radioactivity in oil and gas waste in the 12 largest oil- and gas-producing states in the country: Alaska, California, Colorado, Louisiana, New Mexico, North Dakota, Ohio, Oklahoma, Pennsylvania, Texas, West Virginia, and Wyoming. The findings, detailed in Appendix A, include the following:

- All 12 states allow oil and gas waste to be disposed of in landfills, and 4 have no limits for levels of radioactivity in landfill waste.
- Only 3 states require the monitoring of landfill leachate for radioactive materials. Leachate, a liquid waste product created as rain or other water seeps through the landfill contents, can eventually reach groundwater or surface water.
- Ten states allow oil and gas wastewater to be spread on roads for uses such as dust suppression or deicing; only 3 of those have standards for acceptable levels of radioactive materials for this practice.
- Most of the states allow oil and gas wastewater to be discharged to surface waters such as rivers and streams; Discharges are subject to state water quality standards, yet only 4 states have standards for radioactive materials. Discharge is also permitted offshore, including coastal waters and territorial seas, for example in the Gulf of Mexico and off Alaska and California.[96]
- Nine states allow wastewater to be used in some form of land application, a category that includes irrigation, spraying onto land, land farming, and road building. Only 3 have radioactive material standards for these practices.
- All 12 states allow oil and gas waste to be buried on well pads, but only 1 has radioactive material limits for this practice.

These findings are consistent with other reports on state regulations. For example, a 2019 EPA study of the 28 top oil- and gas-producing states—representing more than 99 percent of annual U.S oil and gas production by volume—found that state regulations for radioactivity are "fragmented" and vary widely from state to state.[97] The EPA found that 6 states do not address radioactivity at all in their regulations and only 10 states have regulations for radioactivity that are specific to oil and gas E&P.

Additionally, a 2015 report from the Conference of Radiation Control Program Directors found that only 16 states have existing radiation protection regulations for the management and disposal of TENORM.[98] And a LawAtlas study found only 16 states with TENORM limits for oil and gas wastes and only 5 states that have provisions for the protection of oil and gas workers regarding TENORM or NORM.[99]

With both the federal government and state governments declining to adequately regulate the radioactive material in oil and gas waste, industry is often free to release this waste into surrounding communities, endangering human health and the environment with impunity.

DEICING WITH RADIOACTIVE WASTEWATER IN OHIO

In 2017 the Ohio Division of Oil and Gas Resources Management commissioned an analysis of the radioactive content of AquaSalina, a commercial road deicing product used in Ohio and made from oil and gas wastewater. The study analyzed samples of the wastewater used to make AquaSalina as well as samples of the finished product and found that its average radioactivity exceeded federal drinking water standards for combined radium-226 and radium-228 "by a factor of 300." It also exceeded Ohio's standards for discharging radium-226 and radium-228 wastewater into rivers or streams.[100] State newspapers reported that AquaSalina had been spread on roads across the state by Ohio Department of Transportation snowplows "for years." Rather than using this information to tighten regulations, the Ohio state legislature considered legislation that would further weaken the rules for reusing oil and gas wastewater in commercial products.[101] While the legislation did not pass, it may be reconsidered in the future. Meanwhile, Ohio used one million gallons of AquaSalina in the winter of 2017–2018 and more than 600,000 gallons from September 2018 to early February 2019.[102]

Recommendations

Oil and gas E&P generates massive amounts of waste. Inadequate regulations for management and disposal of this waste expose Americans to potentially harmful radioactive material. Despite this clear danger, the federal government has allowed the industry to avoid meaningful regulation, and states have not stepped up to fill the gaps in federal oversight. To protect public health and communities from the dangers of NORM and TENORM:

1. **Congress** must close the oil and gas gaps in our federal laws so that oil and gas companies have to comply with the same laws that apply to other industries. Legislation should also establish a uniform definition of NORM and TENORM and create a cradle-to-grave statutory and regulatory framework for managing radioactive oil and gas material to best minimize harms to human health and the environment.

2. **States** should have comprehensive, state-of-the-art, protective regulations for the radioactive material generated by the oil and gas industry. The Conference of Radiation Control Program Directors has developed suggested state regulations for control of TENORM that can be used a starting point.[103] State regulations should include standards for worker exposure, monitoring, and right to know; worker training; site monitoring of surface, groundwater, and air emissions; site safety including postings, labeling, and equipment surveys; baseline surveys of land and water; site cleanup and reuse; data collection and recordkeeping; waste management, transfer, and disposal; reporting of spills and other releases; site access; enforcement authority; financial assurances; abandoned wells; and more.

3. **Industry** should be required to provide baseline worker protections including adequate formal training on radiation safety so workers understand hazards associated with TENORM and how to avoid and prevent them. Also, workplace standards should be established to protect workers from harm, including mandated use of protective clothing to reduce the risk of transferring contamination and suitable respiratory protective equipment to prevent inhalation of any likely airborne radioactive contamination. Standards should also be set for the confinement of NORM or TENORM to prevent release into the environment.[104]

Appendix A: State Regulations for Radioactive Material in Oil and Gas Exploration and Production

	AK	CA	CO[105]	LA[106]	NM[107]	ND[108]	OH[109]	OK[110]	PA[111]	TX[112]	WV[113]	WY[114]
Accepted at solid waste landfills?	Yes, landfills can accept concentrations less than or equal to 5 pCi/g of Ra-226 plus Ra-228. Facilities may be licensed to accept higher levels.[115]	Yes, landfills can accept drilling waste.[116] No specific limitations for TENORM.	Yes, landfills can accept concentrations not in excess of 50 pCi/g each in dry weight of Ra-226, Ra-228, Lead-210, and Polonium-210, excluding natural background.[117] One landfill is licensed to accept higher levels.[118]	Yes, landfills can accept concentrations not exceeding 30 pCi/g of Ra-226 or Ra-228.[119] Facilities may be licensed to accept TENORM not exceeding 200 pCi/g of Ra-226 or Ra-228 and daughter products.[120]	Yes, landfills can accept concentrations of 30 pCi/g or less of Ra-226 above background, or 150 pCi/g or less of any other NORM radionuclide above background.[121] Higher levels can be permitted with approval.[122]	Yes, landfills can accept up to, but not exceeding, 50.0 pCi/g of Ra-226 plus Ra-228; must not exceed 25,000 tons per year or 3,000 tons per month.[123]	Yes, landfills can accept concentrations less than 5 pCi/g above natural background of Ra-226, Ra-228, or any combination of Ra-226 and Ra-228.[124] Drill cuttings are excluded from the definition of TENORM.[125]	Yes, landfills can accept. No standards for TENORM.[126]	Yes, landfills can accept with agency approval.[127] Each landfill has an approved waste acceptance plan that is specific to each facility and identifies concentration-based limits for individual constituents.[128]	Yes, landfills can accept at concentrations of 30 pCi/g or less of Ra-226 or Ra-228 or 150 pCi/g or less of any other NORM radionuclide.[129]	Yes, landfills can accept drilling waste if the combined concentration of Ra-226 and Ra-228 is less than 5 pCi/g above background.[130] Completion and production wastes from horizontal gas wells can be accepted if the combined concentration of Ra-226 and Ra-228 is less than or equal to 50 pCi/g.[131]	Yes, landfills can accept. No regulatory standards for TENORM.[132]
	AK	CA	CO	LA	NM	ND	OH	OK	PA	TX	WV	WY
Standards for leachate from landfills?	No TENORM regulations for leachate.	No TENORM regulations for leachate.	Leachate must be sampled for each TENORM isotope received by the facility. Isotopes detected in excess of groundwater standards must be included in groundwater monitoring.[133]	No TENORM regulations for leachate.	No TENORM regulations for leachate.	Leachate from TENORM waste must be sampled for radon, combined Ra-226 and Ra-228, and alpha particle activity. Radionuclides detected above specified levels must be included in groundwater monitoring.[134]	No TENORM regulations for leachate.	No TENORM regulations for leachate.	Leachate must be sampled for chemical composition but there is no required sampling of radionuclides.[135]	No TENORM regulations for leachate.	Landfills accepting drilling waste must analyze the characteristics of all leachates.[136] Leachate from drilling waste from horizontal wells must be sampled for total Ra-226 and total Ra-228.[137]	No TENORM regulations for leachate.

	AK	CA	CO	LA	NM	ND	OH	OK	PA	TX	WV	WY
Road spreading allowed?	Not addressed in regulations; beneficial use projects can be authorized with no standards for TENORM.[138]	Allowed, required monitoring includes Ra-226 and Ra-228.[139]	Water-based bentonitic drilling fluids allowed on lease roads,[140] up to 50 pCi/g each in dry weight of Radium-226, Radium-228, Lead-210, and Polonium-210, excluding natural background.[141]	Allowed on lease roads subject to applicable NORM criteria or limits.[142]	Not permitted.[143]	Allowed, concentration of Ra-226 plus Ra-228 must be below 5 pCi/g.[144]	Allowed, no standards for TENORM.[145]	Allowed, no standards for TENORM.[146]	Allowed from conventional wells only, no standards for TENORM.[147]	Prohibited.[148]	Allowed, no standards for TENORM.[149]	Allowed, produced water and produced water-contaminated soils require sampling for Ra-226.[150]
	AK	**CA**	**CO**	**LA**	**NM**	**ND**	**OH**	**OK**	**PA**	**TX**	**WV**	**WY**
Land application other than roads or commercial facilities?	Not addressed in regulations; beneficial use projects can be authorized. No standards for TENORM.[151]	Allowed, standards for radioactivity vary by location.[152]	Water treatment residuals can be applied to land and shall not exceed 25 pCi/g each of Radium-226, Radium-228, Lead-210, and Polonium-210.[153]	Allowed, subject to NORM limits.[154]	Not permitted.[155]	Not addressed in regulations.	Not addressed in regulations.[156]	Allowed, no standards for TENORM.[157]	Allowed, no standards for TENORM.[158]	Allowed on site if, after NORM waste is applied to and mixed with land, it does not exceed 30 pCi/g Ra-226 combined with Ra-228 or 150 pCi/g of any other radionuclide.[159] Not permitted.	Allowed, no standards for TENORM.[160]	Allowed, no standards for TENORM.[161]
	AK	**CA**	**CO**	**LA**	**NM**	**ND**	**OH**	**OK**	**PA**	**TX**	**WV**	**WY**
Burial on well pad allowed?	Allowed, no standards for TENORM.[162]	Allowed, no standards for TENORM.[163]	Allowed, no standards for TENORM.[164]	Allowed, no standards for TENORM.[165]	Allowed, no standards for TENORM.[166]	Allowed, no standards for TENORM.[167]	Allowed, waste from wells defined as horizontal must be tested for TENORM.[168] Drill cuttings are excluded from the definition of TENORM.[169]	Allowed, no standards for TENORM.[170]	Permit required, no standards for TENORM.[171]	Allowed if radioactivity concentration does not exceed 30 pCi/g Ra-226 combined with Ra-228 or 150 pCi/g of any other NORM radionuclide.[172] Not permitted.	Allowed, no standards for TENORM.[173]	Allowed, no standards for TENORM.[174]

	AK	CA	CO	LA	NM	ND	OH	OK	PA	TX	WV	WY
Discharge of raw or treated oil and gas wastewater to surface water allowed (NPDES)?	Not permitted.[175]	Not currently permitted.[176]	Allowed, subject to standards for TENORM.[177]	Allowed, no standards for TENORM.[178]	Not permitted.	Not permitted.[179]	Can be authorized by Ohio Department of Natural Resources.[180]	Allowed, not currently permitted.[181]	Allowed, no standards for TENORM.[182]	Allowed,[183] subject to standards for radionuclides.[184]	Allowed, subject to standards for radioactivity.[185]	Allowed,[186] subject to standards for radioactivity.[187]
	AK	CA	CO	LA	NM	ND	OH	OK	PA	TX	WV	WY
Limits on TENORM for Class II UIC fluids?	No limits on TENORM.[188]	No limits on TENORM.[189]	No limits on TENORM. Required fluid analysis for applications includes Ra-226 and Ra-228.[190]	No limits on TENORM. Operators must annually report whether NORM was injected.[191]	No limits on TENORM.[192]	No limits on TENORM.[193]	No limits on TENORM.[194]	No limits on TENORM.[195]	Class II UIC wells in Pennsylvania are regulated by U.S. EPA; no limits on TENORM.[196]	No limits on TENORM, but permit must specifically allow NORM unless concentrations are 30 pCi/gm or less of Ra-226 or Ra-228 or 150 pCi/gm or less of any other NORM radionuclide.[197] Applications must include the volume or proposed rate of disposal and the maximum measured radioactivity level of each radionuclide to be injected.[198]	No limits on TENORM.[199] Required fluid analysis for applications includes NORM.[200]	No limits on TENORM.[201]

Appendix B: NRDC Soil and Water Sample Analysis

More testing must be done on oil and gas production and waste sites to determine radioactivity levels. NRDC conducted a series of tests that can serve as a methodological example for how this testing can be done.

In June 2019, NRDC toured Ohio, West Virginia, and Pennsylvania to explore TENORM issues in oil and gas production. NRDC staff collected 37 samples, including 22 soil and sediment samples, 14 surface water samples, and one produced water sample to understand radiation levels in locations selected on the basis of proximity to areas associated with oil and gas waste management. These locations included sites near a landfill containing TENORM, injection wells, and wastewater treatment facilities. Analysis of the collected samples focused on the two isotopes of radium (radium-226 and radium-228) that are important components of TENORM in terms of potential human health effects. Consequently, the evaluation presented here focuses on these radioactive materials.

Samples were collected in appropriate laboratory containers, labeled, packaged, and placed in coolers. All necessary information for the samples was tracked using a chain of custody form. Each sample was assigned a unique number to identify information such as location, type, and date of sampling. TestAmerica Laboratories, Inc., based in Earth City, Missouri, provided sample containers and coolers to support this effort.

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Water sampling in West Virginia.

The analysis showed that the produced water sample had elevated levels of radiation (3,055 pCi/l total radium).

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Produced water sample.

Table B-1 presents radium-226 and radium-228 concentrations in produced water obtained from NRDC sample analysis and data from other studies.[202] As it shows, studies have found produced water from the Marcellus Shale with combined radium (Ra-226 and Ra-228) concentrations as high as 5,490 pCi/l. For comparison, the EPA maximum contaminant level for drinking water is 5 pCi/l for total radium.

TABLE B-1: RADIOACTIVITY IN PRODUCED WATER

	Total Radium (Radium-226 + Radium-228) in pCi/l
NRDC data	3,055
Non-Marcellus Shale	1,011
Marcellus Shale	2,460
Marcellus Shale, New York State	5,490

The radioactivity level of radium seen in produced water could be of potential health concern if the water is spilled, leaked, or discharged to surface water in large quantities. It is also an indicator that the oil and gas industry should follow best practices to protect workers from the harmful effects of radiation.

Although NRDC's soil and surface water sample results did not show elevated levels of radioactivity, studies have shown contamination of local surface water resources from produced water leaks and spills in other locations.[203]

ENDNOTES

1 International Atomic Energy Agency (hereinafter IAEA), *Radiation Protection and the Management of Radioactive Waste in the Oil and Gas Industry*, Safety Reports Series No. 34, 2003, https://www-pub.iaea.org/MTCD/publications/PDF/Pub1171_web.pdf.

2 U.S. Environmental Protection Agency (hereinafter EPA), "TENORM: Oil and Gas Production Wastes," last updated February 23, 2021, https://www.epa.gov/radiation/tenorm-oil-and-gas-production-wastes.

3 EPA, *Report to Congress: Management of Wastes From the Exploration, Development, and Production of Crude Oil, Natural Gas, and Geothermal Energy*, Volume 1 of 3, EPA/530-SW-88-003, December 1987, https://archive.epa.gov/epawaste/nonhaz/industrial/special/web/pdf/530sw88003a.pdf.

4 EPA, "Radionuclides Rule," last updated November 1, 2016, https://www.epa.gov/dwreginfo/radionuclides-rule.

5 Keith Schneider, "Radiation Danger Found in Oilfields Across the Nation," *New York Times*, December 3, 1990, A1, https://www.nytimes.com/1990/12/03/us/radiation-danger-found-in-oilfields-across-the-nation.html.

6 Ibid.

7 Association of State and Territorial Solid Waste Management Officials, *Waste Generation and Disposal: Awareness, Management, and Disposal Guidance for Solid Waste Containing Technologically Enhanced Naturally Occurring Radioactive Material (TENORM)*, February 2018, 3-6, http://astswmo.org/files/Resources/Materials_Management/Final-TENORM-Document-Feb-2018.pdf.

8 U.S. Energy Information Administration (hereinafter EIA), "U.S. Field Production of Crude Oil," March 31, 2021, https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=MCRFPUS1&f=A; "U.S. Natural Gas Gross Withdrawals," March 31, 2021, https://www.eia.gov/dnav/ng/hist/n9010us2a.htm.

9 EIA, *The Distribution of U.S. Oil and Natural Gas Wells by Production Rate*, December 2020, https://www.eia.gov/petroleum/wells/pdf/full_report.pdf.

10 John Veil, *U.S. Produced Water Volumes and Management Practices in 2017*, Ground Water Research and Education Foundation, February 2020, http://www.veilenvironmental.com/publications/pw/pw_report_2017_final.pdf.

11 Lindsey Konkel, "In the Neighborhood of 18 Million: Estimating How Many People Live Near Oil and Gas Wells," *Environmental Health Perspectives* 125, no. 12 (December 2017), https://ehp.niehs.nih.gov/doi/full/10.1289/EHP2553.

12 National Council on Radiation Protection and Measurements, Commentary No. 29: "Naturally Occurring Radioactive Material (NORM) and Technologically Enhanced NORM (TENORM) From the Oil and Gas Industry," April 22, 2020; overview at https://ncrponline.org/wp-content/themes/ncrp/PDFs/Product-attachments/29/overview.pdf.

13 Julie Grant, "Fracking Wastewater From Pa. Often Ends Up in Ohio. Some Residents Say They've Had Enough," StateImpact Pennsylvania, October 12, 2018, https://stateimpact.npr.org/pennsylvania/2018/10/12/fracking-wastewater-from-pa-usually-ends-up-in-ohio-some-residents-say-theyve-had-enough/.

14 Khalid ALNabhani, Faisal Khan, and Min Yang, "Management of TENORMs Produced During Oil and Gas Operation," *Journal of Loss Prevention in the Process Industries* 47 (March 2017): 161-8, https://doi.org/10.1016/j.jlp.2017.03.016.

15 EPA, "Technologically Enhanced Naturally Occurring Radioactive Materials (TENORM)," last updated March 10, 2020, https://www.epa.gov/radiation/technologically-enhanced-naturally-occurring-radioactive-materials-tenorm.

16 Argonne National Laboratory Environmental Science Division, *Radiological and Chemical Fact Sheets to Support Health Risk Analyses for Contaminated Areas*, March 2007, https://www.remm.nlm.gov/ANL_ContaminantFactSheets_All_070418.pdf.

17 EPA, "Health Risk of Radon," https://www.epa.gov/radon/health-risk-radon#:~:text=Radon%20is%20the%20number%20one,people%20who%20have%20never%20smoked (accessed April 13, 2021).

18 IAEA, *Radiation Protection.*

19 See, e.g., Marguerite M. Nyhan et al., "Associations Between Ambient Particle Radioactivity and Lung Function," *Environment International* 130 (September 2019): 104795, https://doi.org/10.1016/j.envint.2019.04.066; Marguerite M. Nyhan et al., "Associations Between Ambient Particle Radioactivity and Blood Pressure: The NAS (Normative Aging Study), *Journal of the American Heart Association* 7, no. 6 (March 2018): e008245, https://www.ahajournals.org/doi/10.1161/JAHA.117.008245; Wenyuan Li et al., "Recent Exposure to Particle Radioactivity and Biomarkers of Oxidative Stress and Inflammation: The Framingham Heart Study," *Environment International* 121, part 2 (December 2018): 1210–16, https://doi.org/10.1016/j.envint.2018.10.039; and Annelise J. Blomberg et al., "The Role of Ambient Particle Radioactivity in Inflammation and Endothelial Function in an Elderly Cohort," *Epidemiology* 31, no. 4 (July 2020): 499-508, https://journals.lww.com/epidem/Abstract/2020/07000/The_Role_of_Ambient_Particle_Radioactivity_in.5.aspx.

20 U.S. Nuclear Regulatory Commission, "Background Radiation," August 25, 2020, https://www.nrc.gov/reading-rm/basic-ref/glossary/background-radiation.html.

21 K. P. Smith, *An Overview of Naturally Occurring Radioactive Materials (NORM) in the Petroleum Industry*, Argonne National Laboratory, Environmental Assessment and Information Sciences Division, December 1992, https://www.evs.anl.gov/publications/doc/ANL_EAIS_7.pdf.

22 Andrew Wyatt Nelson, *Naturally Occurring Radioactive Materials Associated With Unconventional Drilling for Natural Gas,* Ph.D. thesis, University of Iowa, 2016, https://ir.uiowa.edu/etd/5579/.

23 Longxiang Li et al., "Unconventional Oil and Gas Development and Ambient Particle Radioactivity," *Nature Communications* 11, article 5002 (2020): 1-8, https://www.nature.com/articles/s41467-020-18226-w.

24 Yanqing Xu, Mounika Sajja, and Ashok Kumar, "Impact of the Hydraulic Fracturing on Indoor Radon Concentrations in Ohio: A Multilevel Modeling Approach," *Frontiers in Public Health* 7, no. 76 (April 2019), doi: 10.3389/fpubh.2019.00076. Joan A. Casey et al., "Predictors of Indoor Radon Concentrations in Pennsylvania, 1989–2013," *Environmental Health Perspectives* 123, no. 11 (November 2015), https://doi.org/10.1289/ehp.1409014.

25 Doug Brugge and Virginia Buchner, "Radium in the Environment: Exposure Pathways and Health Effects," *Reviews on Environmental Health* 27, no. 1 (2012): 1-17, https://doi.org/10.1515/reveh-2012-0001.

26 Christopher B. Harto et al., *Radiological Dose and Risk Assessment of Landfill Disposal of Technologically Enhanced Naturally Occurring Radioactive Materials (TENORM) in North Dakota*, Argonne National Laboratory, Environmental Science Division, November 2014, https://www.evs.anl.gov/downloads/ANL-EVS-14_13-NDDH-TENORM-Landfill-Study.pdf. See also "Assessment of TENORM Disposal in North Dakota Industrial Waste and Special Waste Landfills," Argonne National Laboratory, public meeting presentation, Williston, North Dakota, January 22, 2015, https://deq.nd.gov/TENORM/Argonne%20ND%20Public%20Outreach%20Slides.pdf.

27 Bloomberg News, "Workers Say Exxon Mobil Hid Cleaning Job's Radiation Risk," updated January 2, 2019, https://www.chron.com/business/energy/article/Workers-say-Exxon-Mobil-hid-cleaning-job-s-1615150.php. See also Jim Orr, "Court Reinstates TENORM Lawsuit for Deceased Pipe Yard Workers Injured by Radioactive Waste," HO&P Legal Blog, November 20, 2014, https://www.hop-law.com/court-reinstates-tenorm-lawsuit-for-deceased-pipe-yard-workers-injured-by-radioactive-waste/.

28 Elizabeth Ann Glass Geltman and Nichole LeClair, "Regulation of Radioactive Fracking Waste," *Vermont Journal of Environmental Law* 19, (August 31, 2017), https://ssrn.com/abstract=3030255.

29 Stanley Waligora and Marvin Resnikoff, "Occupational Exposures to Radioactive Scale and Sludge: Coleman et al v. H.C. Price Co., et al.," Radioactive Waste Management Associates, December 2013, https://www.documentcloud.org/documents/6759784-OCCUPATIONAL-EXPOSURES-to-RADIOACTIVE-SCALE-and.html.

30 Nancy Lauer, Nathaniel Warner, and Avner Vengosh, "Sources of Radium Accumulation in Stream Sediments Near Disposal Sites in Pennsylvania: Implications for Disposal of Conventional Oil and Gas Wastewater," *Environmental Science & Technology* 52, no. 3 (January 2018): 955-62, DOI: 10.1021/acs.est.7b04952.

31 EPA, "Radiation Basics," last updated August 10, 2017, https://www.epa.gov/radiation/radionuclides.

32 Lauren Donovan, "Potentially Radioactive Material Spilling Out of Trailers Near Watford City," *Bismarck Tribune*, February 22, 2014, https://bismarcktribune.com/bakken/potentially-radioactive-material-spilling-out-of-trailers-near-watford-city/article_dbc501c6-9bd4-11e3-b001-0019bb2963f4.html.

33 Lauren Donovan, "Radioactive Dump Site Found in Remote North Dakota Town." *Bismarck Tribune*, March 11, 2014, https://bismarcktribune.com/bakken/radioactive-dump-site-found-in-remote-north-dakota-town/article_39d0d08a-a948-11e3-8a3b-001a4bcf887a.html#:~:text=This%20photo%20show%20the%20inside,waste%20byproduct%20of%20oil%20production.

34 Sarah Jane Keller, "North Dakota Wrestles With Radioactive Oilfield Waste," *High Country News*, July 14, 2014, https://www.hcn.org/articles/north-dakota-wrestles-with-radioactive-oilfield-waste.

35 North Dakota Administrative Code 33-20-11. See North Dakota Department of Health, "TENORM Information Sheet," December 2014, https://deq.nd.gov/tenorm/InformationFactSheets/NDDoH%20TENORM%20INFORMATION%20SHEET-v.FINAL.pdf.

36 Letter to operators from Bruce E. Hicks, assistant director, North Dakota Department of Mineral Resources, Oil and Gas Division, "Re: Filter Socks and Other Filter Media, Leakproof Container Required, Oil and Gas Wells," April 9, 2014, https://www.dmr.nd.gov/oilgas/Letter.Filter%20Socks.Container.Oil%20Well.2014-04-09.pdf. Letter to operators from Bruce E. Hicks, assistant director, North Dakota Department of Mineral Resources, Oil and Gas Division, "Re: Filter Socks and Other Filter Media, Leakproof Container Required, SWD Wells," April 9, 2014, https://www.dmr.nd.gov/oilgas/Letter.Filter%20Socks.Container.SWD%20Well.2014-04-09.pdf.

37 Nancy E. Lauer, Jennifer S. Harkness, and Avner Vengosh, "Brine Spills Associated With Unconventional Oil Development in North Dakota," *Environmental Science & Technology* 50, no. 10 (April 2016): 5389-97, DOI: 10.1021/acs.est.5b06349; See also Cozzarelli, I.M et al, "Environmental Signatures and Effects of an Oil and Gas Wastewater Spill in the Williston Basin, North Dakota," *Science of the Total Environment* 579 (February 2017): 1781-93, https://doi.org/10.1016/j.scitotenv.2016.11.157.

38 Laura Gunderson, "Oregon Landfill Accepted 2 Million Pounds of Radioactive Fracking Waste From North Dakota," *The Oregonian*, February 13, 2020, https://www.oregonlive.com/environment/2020/02/oregon-landfill-accepted-2-million-pounds-of-radioactive-fracking-waste-from-north-dakota.html.

39 Jared Thompson et al., *E-42 Task Force Report: Review of TENORM in the Oil & Gas Industry*, Conference of Radiation Control Program Directors, June 2015, 45, https://cdn.ymaws.com/www.crcpd.org/resource/collection/89CD4979-9A4C-41AF-8832-2F1EA116A8C0/E-42_Report_Review_of_TENORM.pdf.

40 Memorandum from Frank Marcinowski, director, Radiation Protection Division, EPA, "Guidance: Potential for Radiation Contamination Associated With Mineral and Resource Extraction Industries," April 15, 2003, https://www.epa.gov/sites/production/files/2015-04/documents/mineguide.pdf.

41 See Elizabeth Ann Glass Geltman and Nichole LeClair, "Regulation of Radioactive Fracking Waste," *Vermont Journal of Environmental Law* 19, 2018, https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3030255.

42 Melissa A. Troutman, *Still Wasting Away: The Failure to Safely Manage Oil and Gas Waste Continues*, Earthworks, May 2019, https://www.earthworks.org/cms/assets/uploads/2019/06/National-Phase-1_WastingAway_2.0-5-2019.pdf. See also EPA, Office of Land and Emergency Management and Office of Resource Conservation and Recovery, *Management of Exploration, Development and Production Wastes: Factors Informing a Decision on the Need for Regulatory Action*, April 2019, https://www.epa.gov/sites/production/files/2019-04/documents/management_of_exploration_development_and_production_wastes_4-23-19.pdf.

43 Thompson et al., *E-42 Task Force Report*.

44 Nelson, *Naturally Occurring Radioactive Materials*.

45 EPA, *Management of Exploration*.

46 Lara O. Haluszczak, Arthur W. Rose, and Lee R. Kump, "Geochemical Evaluation of Flowback Brine From Marcellus Gas Wells in Pennsylvania, USA," *Applied Geochemistry* 28 (January 2013): 55-61, https://doi.org/10.1016/j.apgeochem.2012.10.002.

47 Ibid. Andrew W. Nelson et al., "Matrix Complications in the Determination of Radium Levels in Hydraulic Fracturing Flowback Water From Marcellus Shale," *Environmental Science & Technology Letters* 1, no. 3 (March 2014): 204-8, https://doi.org/10.1021/ez5000379.

48 EPA, *Management of Exploration*.

49 Nelson, *Naturally Occurring Radioactive Materials*.

50 EPA, "TENORM: Oil and Gas Production Wastes."

51 EPA, *Management of Exploration*.

52 Austyn Gaffney, "A Small Town's Battle Against Radioactive Fracking Waste," *onEarth*, January 9, 2019, https://www.nrdc.org/onearth/small-towns-battle-against-radioactive-fracking-waste.

53 Thompson et al., *E-42 Task Force Report*, 12.

54 EPA, "Summary of the Resource Conservation and Recovery Act," last updated July 28, 2020, https://www.epa.gov/laws-regulations/summary-resource-conservation-and-recovery-act.

55 42 U.S.C. § 6903(5).

56 42 U.S.C. § 6921(b)(2)(B). EPA, Office of Solid Waste, *Exemption of Oil and Gas Exploration and Production Wastes From Federal Hazardous Waste Regulations*, October 2002, https://archive.epa.gov/epawaste/nonhaz/industrial/special/web/pdf/oil-gas.pdf. See also 42 U.S.C. § 6921(b)(2)(A).

57 Regulatory Determination for Oil and Gas and Geothermal Exploration, Development and Production Wastes, 53 Fed. Reg. 25447, 25448 (July 6, 1988).

58 Ibid.

59 Jennifer Dixon, "EPA Said to Bow to Political Pressure in Oil Wastes Ruling," Associated Press, July 19, 1988, https://www.apnews.com/87790d67435a0ba3eb1e5ecc5ce86c9c.

60 42 U.S.C. § 6903(27).

61 Environmental Integrity Project et al. v. McCarthy, 16-cv-842 (JDB) (D.D.C. filed May 4, 2015), ECF No. 1, https://environmentalintegrity.org/wp-content/uploads/2016-05-04-RCRA-OG-Wastes-Deadline-Suit-Complaint-FILED.pdf.

62 See EPA, Office of Solid Waste, *Exemption of Oil and Gas Exploration,* at 8. There, the EPA goes to significant pains to describe what is and what is not exempt from RCRA: "In general, the exempt status of an E&P waste depends on how the material was used or generated as waste, not necessarily whether the material is hazardous or toxic. For example, some exempt E&P wastes might be harmful to human health and the environment, and many non-exempt wastes might not be as harmful. The following simple rule of thumb can be used to determine if an E&P waste is exempt or non-exempt from RCRA Subtitle C regulations: Has the waste come from down-hole, i.e., was it brought to the surface during oil and gas E&P operations? Has the waste otherwise been generated by contact with the oil and gas production stream during the removal of produced water or other contaminants from the product? If the answer to either question is yes, then the waste is likely considered exempt from RCRA Subtitle C regulations."

63 U.S. Nuclear Regulatory Commission, "Atomic Energy Act of 1954, as Amended in NUREG-0980," https://www.nrc.gov/about-nrc/governing-laws.html.

64 10 C.F.R. § 40.13.

65 Transportation of Radioactive Materials: Memorandum of Understanding, 44 Fed. Reg. 38690 (July 2, 1979).

66 These rules are found at 10 C.F.R. part 71.

67 Letter from Charles Betts, director, Standards and Rulemaking Division, U.S. Department of Transportation Pipeline and Hazardous Materials Safety Administration, to William Dawson, business development manager, MHF Services, Ref. No. 13-0157, December 19, 2013, https://www.phmsa.dot.gov/sites/phmsa.dot.gov/files/legacy/interpretations/Interpretation%20Files/2013/130157.pdf.

68 Justin Nobel, "America's Radioactive Secret," *Rolling Stone*, January 21, 2020, https://www.rollingstone.com/politics/politics-features/oil-gas-fracking-radioactive-investigation-937389/.

69 Bonnie McDevitt et al., "Emerging Investigator Series: Radium Accumulation In Carbonate River Sediments at Oil and Gas Produced Water Discharges: Implications for Beneficial Use as Disposal Management," *Environmental Science: Processes & Impacts*, no. 2 (February 2019), https://doi.org/10.1039/C8EM00336J.

70 Memorandum from Stephen Luftig, Director, Office of Emergency and Remedial Response, and Larry Weinstock, Acting Director, Office of Radiation and Indoor Air, EPA, "Use of Soil Cleanup Criteria in 40 CFR Part 192 as Remediation Goals for CERCLA Sites," Directive no. 9200.4-25, 1998, https://ntrl.ntis.gov/NTRL/dashboard/searchResults/titleDetail/PB97963308.xhtml.

71 29 C.F.R. § 910.1096.

72 Letter from Richard E. Fairfax, Director, Directorate of Enforcement Programs, Occupational Safety and Health Administration, to Connie K. DeWitte, Chief, Safety and Occupational Health Office, Department of the Army, Standard Number 1910.1096, December 23, 2002, https://www.osha.gov/laws-regs/standardinterpretations/2002-12-23. See also Robert K. Lewis, "Radon in the Workplace, The OSHA Ionizing Radiation Regulations," Pennsylvania Department of Environmental Protection, Bureau of Radiation Protection, http://aarst-nrpp.com/proceedings/2004/2004_07_Radon_in_the_Workplace_The_OSHA_Ionizing_Radiation.pdf (accessed April 13, 2021).

73 70 Fed. Reg. 22828 (May 3, 2005), http://hps.org/govtrelations/documents/osha_rfi_fr.pdf.

74 Veil*, U.S. Produced Water Volumes.*

75 EPA, "Summary of the Clean Water Act," last updated September 9, 2020, https://www.epa.gov/laws-regulations/summary-clean-water-act.

76 EPA, "The NPDES General Permit for New and Existing Sources and new Dischargers in the Offshore Subcategory of the Oil and Gas Extraction Point Source Category for the Western Portion of the Outer Continental Shelf of the Gulf of Mexico (GMG290000)," September 19, 2017.

77 EPA, "Unconventional Oil and Gas Extraction Effluent Guidelines," last updated February 21, 2021, https://www.epa.gov/eg/unconventional-oil-and-gas-extraction-effluent-guidelines.

78 William D. Burgos et al., "Watershed-Scale Impacts From Surface Water Disposal of Oil and Gas Wastewater in Western Pennsylvania," *Environmental Science & Technology* 51, no. 15 (July 12, 2017): 8851-60, DOI: 10.1021/acs.est.7b01696.

79 Lauer, Warner, and Vengosh, "Sources of Radium Accumulation."

80 Deirdre Lockwood, "Oil And Gas Wastewater Leaves Radium in Pennsylvania Stream Sediments," *Chemical & Engineering News*, February 6, 2018, https://cen.acs.org/articles/96/web/2018/02/Oil-gas-wastewater-leaves-radium.html.

81 Reid Frazier, "Study: Conventional Drilling Waste Responsible for Radioactivity Spike in Rivers," StateImpact Pennsylvania, January 20, 2018, https://stateimpact.npr.org/pennsylvania/2018/01/20/study-conventional-drilling-waste-responsible-for-radioactivity-spike-in-rivers/.

82 Reid Frazier, "How Did Fracking Contaminants End Up in the Monongahela River? A Loophole in the Law Might Be to Blame," StateImpact Pennsylvania, September 11, 2019, https://stateimpact.npr.org/pennsylvania/2019/09/11/how-did-fracking-contaminants-end-up-in-the-monongahela-river-a-loophole-in-the-law-might-be-to-blame/. Ken Dufalla, "Major Problems With the Mighty Mon," *Greene County Messenger*, February 15, 2019, https://www.heraldstandard.com/gcm/opinion/natures_corner/major-problems-with-the-mighty-mon/article_bd47ec34-2e34-11e9-a5fb-33cb3191d892.html.

83 Deirdre Lockwood, "Oil and Gas Wastewater Is a Cheap Fix for Road Dust but Comes at a Toxic Cost, *Chemical & Engineering News*, June 21, 2018, https://cen.acs.org/environment/pollution/Oil-gas-wastewater-cheap-fix/96/web/2018/06.

84 EPA, Safe Drinking Water Act (SDWA), last updated October 6, 2020, https://www.epa.gov/sdwa.

85 EPA, "Underground Injection Control Well Classes," last updated September 16, 2016, https://www.epa.gov/uic/underground-injection-control-well-classes.

86 Energy Policy Act of 2005, §322, amending 42 U.S.C. § 300h(d).

87 EPA, "Initial List of Hazardous Air Pollutants With Modifications," last updated June 18, 2020, https://www.epa.gov/haps/initial-list-hazardous-air-pollutants-modifications.

88 42 USC § 7412(n)(4).

89 Ibid. See Joel Minor, "Completing the Bridge to Nowhere: Prioritizing Oil and Gas Emissions Regulations in Western States," 34 *Stanford Environmental Law Journal* 34, no. 1 (2015): 98–99, https://law.stanford.edu/publications/completing-the-bridge-to-nowhere-prioritizing-oil-and-gas-emissions-regulations-in-western-states/ ("In May 2014, sixty-four environmental and public health groups petitioned the EPA to list oil and gas production wells and associated equipment as an area source in parts of six states. To date, the EPA has not responded to the petition.").

90 Roger Alford, "Town Worries About Radiation," *Washington Post*, August 21, 2005, https://www.washingtonpost.com/archive/politics/2005/08/21/town-worries-about-radiation/65ec71e3-bd2f-4e0e-b186-9128d914d8e9/.

91 Stuart H. Smith, *Crude Justice* (Dallas: BenBella Books, 2015).

92 Henry Spitz, Kennith Lovins, and Christopher Becker, "Evaluation of Residual Soil Contamination From Commercial Oil Well Drilling Activities and Its Impact on the Naturally Occurring Background Radiation Environment," *Journal of Soil Contamination* 6, no. 1 (1997): 37-59, DOI: 10.1080/15320389709383545.

93 Stanley J. Waligora Jr. and Marvin Resnikoff, "Radioactive and Toxic Chemical Contamination in the Martha Oil Field, Kentucky, Due to Technologically Enhanced Naturally Occurring Radioactive Material and Toxic Chemicals and Metals, Supplementary Report, In reference to: Ballard Ray, *et al* Vs Ashland Oil Inc. and Ashland Exploration, Inc., Commonwealth of Kentucky, Johnson Circuit Court, Division No. II, Civil Action No. 97-CI-442, Lawrence Circuit Court C.A. No. 97-CI-222," January 8, 2008.

94 Association of State and Territorial Solid Waste Management Officials, *Waste Generation and Disposal: Awareness, Management, and Disposal Guidance for Solid Waste Containing Technologically Enhanced Naturally Occurring Radioactive Material (TENORM)*, February 15, 2018, 6, http://astswmo.org/files/Resources/Materials_Management/Final-TENORM-Document-Feb-2018.pdf.

95 Gaffney, "A Small Town's Battle."

96 40 CFR 435.

97 EPA, *Management of Oil and Gas Exploration, Development and Production Wastes: Factors Informing a Decision on the Need for Regulatory Action*, April 2019, 6-26–6-28, https://www.epa.gov/sites/production/files/2019-04/documents/management_of_exploration_development_and_production_wastes_4-23-19.pdf.

98 Thompson et al., *E-42 Task Force Report*, 48-53.

99 Elizabeth Ann Glass Geltman, "Regulation of Oil & Gas Wastes Containing TENORM," Policy Surveillance Program, December 1, 2016, http://lawatlas.org/datasets/regulation-of-wastes-containing-tenorm.

100 Ohio Division of Oil and Gas Resources Management, Radiation Safety Section, "Assessment of Ra226 & Ra228 Radioactivity in AquaSalina," interoffice memorandum, July 26, 2017, and attached *Radiological Assessment Special Report*, https://columbusfreepress.com/sites/default/files/associated/ODNR%20lab%20tests%20%281%29.pdf.

101 Dave Nethers, "Is a Solution for Battling Ice on Our Roads Too Dangerous?," Fox 8 Cleveland, February 11. 2019, https://fox8.com/2019/02/11/is-a-solution-for-battling-ice-on-our-roads-too-dangerous/.

102 James McCarty, "Radioactive Road Deicer Rules Under Review by Ohio Legislature; Debate Over Public Safety Continues," *Cleveland Plain Dealer*, February 9, 2019, https://www.cleveland.com/metro/2019/02/ohio-legislature-prepares-to-address-law-for-radioactive-road-deicer.html.

103 Conference of Radiation Control Program Directors, Inc., Suggested State Regulations for Control of Radiation, Part N: *Regulation and Licensing of Technologically Enhanced Naturally Occurring Radioactive Material (TENORM)*, April 2004, https://cdn.ymaws.com/www.crcpd.org/resource/resmgr/docs/SSRCRs/N_04-04-print.pdf.

104 IAEA, *Radiation Protection and the Management of Radioactive Waste in the Oil and Gas Industry*, Training Course Series 40, 2010, https://www-pub.iaea.org/MTCD/Publications/PDF/TCS-40_web.pdf.

105 Colorado defines TENORM as "naturally occurring radioactive material whose radionuclide concentrations are increased by or as a result of past or present human practices. 'TENORM' does not include (I) background radiation or the natural radioactivity of rocks or soils; (II) 'byproduct material' or 'source material,' as defined by Colorado statute or rule; or (III) enriched or depleted uranium as defined by Colorado or federal statute or rule." Colo. Rev. Stat. 25-11-201(1)(f).

106 Louisiana regulations define both NORM and TENORM. NORM is defined as "any nuclide that is radioactive in its natural physical state (i.e., not man-made) or that has been made radioactive by exposure to an accelerator beam. This material does not include source, byproduct, or special nuclear material." TENORM is referred to as "TENR" and defined as "natural sources of radiation that would not normally appear without some technological activity not expressly designed to produce radiation." La. Admin. Code 33:XV.102.

107 New Mexico does not define TENORM but defines NORM to mean "the naturally occurring radioactive materials regulated by 20.3.14 NMAC." N.M. Code R. § 19.15.2.7. N.M. Code R. § 20.3.14 defines NORM as "any nuclide which is radioactive in its natural physical state (i.e., not manmade) but does not include byproduct, source or special nuclear material," and defines "regulated NORM" as "NORM contained in any oil-field soils, equipment, sludges or any other materials related to oil-field operations or processes exceeding the radiation levels specified in [Section] 1403." N.M. Code R. § 20.3.14.7(J) and (N).

108 North Dakota defines TENORM as "naturally occurring radioactive material whose radionuclide concentrations are increased by or as a result of past or present human practices. TENORM does not include background radiation or the natural radioactivity of rocks or soils. TENORM does not include 'source material' and 'byproduct material' as both are defined in the Atomic Energy Act of 1954, as amended [42 U.S.C. 2011 et seq.] and relevant regulations implemented by the United States nuclear regulatory commission." N.D. Admin. Code 33-10-23-03(15).

109 Ohio regulations define TENORM as: "naturally occurring radioactive material whose radionuclide concentrations are increased by or as a result of past or present human practices. TENORM does not include drill cuttings, or natural background radiation. TENORM does not include 'source material' and 'byproduct material' as both are defined in rule 3701:1-38-01 of the Administrative Code." Ohio Admin. Code 3701:1-43-01(H).

110 Oklahoma's approved waste management practices for each type of waste are summarized in the chart at Okla. Admin. Code § 165:10-7-24.

111 Pennsylvania regulations state "A technologically enhanced naturally occurring radioactive material is not subject to regulation under the laws of the Commonwealth or the Atomic Energy Act, whose radionuclide concentrations or potential for human exposure have been increased above levels encountered in the natural state by human activities." 25 Pa. Code § 287.1.

112 Texas regulations do not define TENORM, but they define NORM as "naturally occurring materials not regulated under the AEA whose radionuclide concentrations have been increased by or as a result of human practices. NORM does not include the natural radioactivity of rocks or soils, or background radiation, but instead refers to materials whose radioactivity is concentrated by controllable practices (or by past human practices). NORM does not include source, byproduct, or special nuclear material. 25 Tex. Admin. Code § 289.259. This definition is essentially the common understanding of TENORM. Texas statute also defines Oil and gas NORM waste. Texas Health and Safety Code § 401.002(27).

113 West Virginia defines TENORM as "naturally occurring radionuclides whose concentrations are increased by or as a result of past or present human practices. TENORM does not include background radiation or the natural radioactivity of rocks or soils. TENORM does not include uranium or thorium in 'source material' as defined in the aea and US NRC regulations." W. Va. CSR § 64-23-16.3.g. The state's regulations also specifically exempt waste with Ra-226 and Ra-228 combined concentrations under 5pCi/g excluding natural background. W. Va. CSR § 64-23-16.4.a. The purposeful dilution of TENORM for the purpose of meeting this exemption requires agency approval. W. Va. CSR § 64-23-16.4.a.

114 Wyoming defines NORM as "Any waste material exceeding the greater of natural background levels found in nearest non-impacted natural soils at the surface or 8 picoCuries per gram (pCi/g) radium-226 and/or decommissioned equipment from crude oil and/or gas operations exceeding 50 microRoentgens per hour (pR/hr) emanation rate at any accessible point." Wyoming Department of Environmental Quality, Guideline #24: Naturally Occurring Radioactive Material (NORM) Management in Wyoming, August 12, 2011, http://deq.wyoming.gov/media/attachments/Solid%20%26%20Hazardous%20Waste/Solid%20Waste/Guidance%20%26%20Standards/SHWD_Solid-Waste_Guidelines-24-Naturally-Occurring-Radioactive-Material-NORM-Management-In-Wyoming_2011-08_gKSRq9d.pdf.

115 Alaska Admin. Code tit. 18 § 85.300(a).

116 See Patrick M. Kelly, "Review of State Oil and Natural Gas Exploration, Development, and Production (E&P) Solid Waste Management Regulations," U.S. Environmental Protection Agency (hereinafter EPA) memorandum, April 2014, Appendix CA-2, https://www.epa.gov/sites/production/files/2016-04/documents/state_summaries_040114.pdf.

117 6 Colo. Code Regs § 1007-1 Part 20.8.1.A.

118 Total Ra-226 and Ra-228 not to exceed 12,200 pCi/g in pipe scale or 6,000 pCi/g in other waste, Pb-210 not to exceed 10,000 pCi/g. Total oil and gas field wastes received for disposal shall not exceed 50,000 tons per year. Colorado Department of Public Health & Environment, "Colorado facilities approved to accept TENORM for disposal," https://cdphe.colorado.gov/tenorm-interim-gov-docs (accessed May 11, 2021).

119 La. Admin. Code 33.XV.1412.B.3.

120 La. Admin. Code 33.XV.1412.B.4.

121 N.M. Code R. § 20.3.14.1403(A).

122 N.M. Code R. § 19.15.35.11.

123 N.D. Admin. Code 33.1-20-11-01.1.

124 Ohio Rev. Code § 3734.02(P)(2).

125 Ohio Rev. Code § 3748.01(X).

126 Okla. Admin. Code § 165:10-7-24(c)(3).

127 25 Pa. Code § 288.201(h)(2).

128 *Public Hearing on Radioactive and Hazardous Waste Loopholes - Impact on Communities, Worker Safety and Public Health, Before the Pennsylvania House Democratic Policy Committee* (2020)(testimony of the Pennsylvania Department of Environmental Protection), https://www.pahouse.com/files/Documents/Testimony/2020-10-16_110553__hdpc101420.pdf.

129 25 Tex. Admin. Code 289.259(d)(1)(A), 16 Tex. Admin. Code 4.614.

130 W. Va. CSR § 33-1-5.6.d.4.

131 W. Va, CSR § 33-1A-3.4.b.

132 While there are no regulations, there are agency guidelines that direct landfills not to accept more than 20 cubic yards of waste with concentrations up to 30 pCi/g of Ra-226 or more than 10 cubic yards of waste with concentrations from 30-50 pCi/g of Ra-226, to notify the DEQ Solid and Hazardous Waste Division for a case-by-case determination of any volumes exceeding these thresholds, and to reject waste with concentrations above 50 pCi/g of Ra-226. Wyoming Department of Environmental Quality, Guideline #24: Naturally Occurring Radioactive Material (NORM) Management in Wyoming, August 12, 2011, http://deq.wyoming.gov/media/attachments/Solid%20%26%20Hazardous%20Waste/Solid%20Waste/Guidance%20%26%20Standards/SHWD_Solid-Waste_Guidelines-24-Naturally-Occurring-Radioactive-Material-NORM-Management-In-Wyoming_2011-08_gKSRq9d.pdf

133 6 Colo. Code Regs § 1007-1 Part 20.8.1.F.5

134 N.D. Admin. Code 33-20-11-04. See also EPA, *Management of Exploration, Development and Production Wastes, Factors Informing a Decision on the Need for Regulatory Action*, April 2019, C-5, https://www.epa.gov/sites/production/files/2019-04/documents/management_of_exploration_development_and_production_wastes_4-23-19.pdf.

135 25 Pa. Code § 288.456(a)(2); 25 Pa. Code § 288.556(a)(2).

136 W. Va. CSR § 33-1-3.8.h.1.

137 W. Va. CSR § 33-1-5.6.b.3; W. Va. CSR § 33-1, Appendix V.

138 Alaska Admin. Code tit. 18 § 60.007.

139 California Regional Water Quality Control Board, Central Valley Region, “Order R5-2017-0034, Waste Discharge Requirements General Order for Oil Field Discharges to Land, General Order Number One,” April 6, 2017, https://www.waterboards.ca.gov/centralvalley/board_decisions/adopted_orders/general_orders/r5-2017-0034.pdf; California Regional Water Quality Control Board, Central Valley Region, “Order R5-2017-0035, Waste Discharge Requirements General Order for Oil Field Discharges to Land, General Order Number Two,” April 6, 2017, https://www.waterboards.ca.gov/centralvalley/board_decisions/adopted_orders/general_orders/r5-2017-0035.pdf; California Regional Water Quality Control Board, Central Valley Region, “Order R5-2017-0036, Waste Discharge Requirements General Order for Oil Field Discharges to Land, General Order Number Three,” April 6, 2017, waterboards.ca.gov/centralvalley/board_decisions/adopted_orders/general_orders/r5-2017-0036.pdf.

140 2 Colo. Code Regs § 404-1(905)(d)(3)(B).

141 6 Colo. Code Regs § 1007-1 Part 20.6.1.G.

142 La. Admin. Code 43 XIX.313.G.

143 New Mexico Environment Department, “Produced Water Management in New Mexico,” p. 19, https://www.env.nm.gov/wp-content/uploads/sites/16/2019/10/Produced-Water-Public-Meeting-Presentation_ENGLISH_FINAL-191015.pdf (accessed May 14, 2021).

144 N.D. Admin. Code 33-24-02-02. See also North Dakota Department of Health, “Guidelines for the Use of Oilfield Salt Brines for Dust and Ice Control,” 2019, https://deq.nd.gov/Publications/WQ/5_SP/OilFieldBrine_20191210_Final.pdf (stating that “a Department-approved brine source may be used for dust and/or ice control as a substitute for commercial products”).

145 Ohio Rev. Code § 1509.226; Ohio Rev. Code § 1509.22(C)(1)(b).

146 Okla. Admin. Code § 165:10-7-22; Okla. Admin. Code § 165:10-7-27; Okla. Admin. Code § 165:10-7-28; Okla. Admin. Code § 165:10-7-29.

147 25 Pa. Code § 78a.70; 25 Pa. Code § 78a.70a.

148 16 Tex. Admin. Code 4.611.

149 WV DEP, Memorandum of Understanding with WV Division of Highways (WVDOH), “WVDOH/WVDEP Salt Brine From Gas Wells Agreement,” December 22, 2011, http://dep.wv.gov/WWE/Documents/WVDOHWVDEP%20Salt%20Brine%20Agreement.pdf.

150 Wyoming DEQ, “Produced Water and Treatment,” http://deq.wyoming.gov/wqd/permitting-2/resources/produced-water-disposal-treatment/ (accessed April 14, 2021). See also Wyoming DEQ, “Facility Information for Road Application of Waste and Wastewater,” March 16, 2016, http://deq.wyoming.gov/media/attachments/Water%20Quality/Permitting/Produced%20Water%20Disposal%20%26%20Treatment/Road-Application-of-Waste-or-Wastewater.pdf. See also John Wagner, Administrator, “Permitting Treatment Facilities and Land Application of Produced Water Including Coal Bed Methane (CBM) Water,” Wyoming DEQ, revised December 1, 2005, http://deq.wyoming.gov/media/attachments/Water%20Quality/Permitting/Produced%20Water%20Disposal%20%26%20Treatment/Policy-13_48_01-Permitting-Trt-%26-Land-App-of-Produced-Water.pdf.

151 18 Alaska Admin. Code tit. 18 § AAC 60.007.

152 California Water Boards, Fact Sheet, Oilfield Water Discharges to Land, February 15, 2019, https://www.waterboards.ca.gov/centralvalley/water_issues/oil_fields/information/disposal_ponds/2019_0215_of_pond_fact_sheet.pdf. See also California Water Boards, Fact Sheet, Frequently Asked Questions about Recycled Oilfield Water for Crop Irrigation, February 15, 2019, https://www.waterboards.ca.gov/centralvalley/water_issues/oil_fields/food_safety/data/fact_sheet/of_foodsafety_fact_sheet.pdf.

153 6 Colo. Code Regs § 1007-1 Part 20.7.2.C

154 La. Admin. Code 43 XIX.303.

155 New Mexico Environment Department, “Produced Water Management in New Mexico,” p. 19, https://www.env.nm.gov/wp-content/uploads/sites/16/2019/10/Produced-Water-Public-Meeting-Presentation_ENGLISH_FINAL-191015.pdf (accessed May 14, 2021).

156 Ohio Admin. Code 3745-599-05(F).

157 Okla. Admin. Code § 165:10-7-19. Okla. Admin. Code § 165:10-7-17. Okla. Admin. Code § 165:10-7-26. Okla. Admin. Code § 165:10-7-28. Okla. Admin. Code § 165:10-7-29.

158 25 Pa. Code § 78a.63a; 25 Pa. Code § 78a.61; 25 Pa. Code § 291.

159 16 Tex. Admin. Code 4.614(d). See also Railroad Commission of Texas, “Railroad Commission Regulations For Disposal Of Oil And Gas NORM,” http://www.rrc.texas.gov/oil-and-gas/applications-and-permits/environmental-permit-types/norm-waste/ (accessed April 20, 2021).

160 West Virginia Department of Environmental Protection, General Water Pollution Control Permit, Permit Number GP-WV-1-88, March 31, 2016, https://dep.wv.gov/oil-and-gas/Documents/Permits%20Posted%20Web/GP-WV-1-88%202016%20Renewal.pdf; West Virginia Department of Environmental Protection, General Water Pollution Control Permit, Permit Number Permit Number GP-WV-1-07, July 31, 2020, https://dep.wv.gov/oil-and-gas/Documents/2020-07-30%20GP-WV-1-07%20Renewal%20Final%20signed.pdf.

161 055.0001.4 Wyo. Code R. § (1)(mm). See also Wagner, “Permitting Treatment Facilities.”

162 Alaska Admin. Code tit. 18 § 60.440.

163 California State Water Resources Control Board, “Water Quality Order No. 2003-0003-DWQ, Statewide General Waste Discharge Requirements (WDRs) for Discharges to Land with a Low Threat to Water Quality (General WDRs),” Section C(2)(b), https://www.waterboards.ca.gov/board_decisions/adopted_orders/water_quality/2003/wqo/wqo2003-0003.pdf (accessed May 12, 2021).

164 2 Colo. Code Regs § 404-1(905)(d)(3); 2 Colo. Code Regs § 404-1(905)(g)(2).

165 La. Admin. Code 43 XIX.311; La. Admin. Code 43 XIX.313.

166 N.M. Code R. § 19.15.17.13(D).

167 N.D. Admin. Code 43-02-03-19.4. N.D. Admin. Code 43-02-03-19.5.

168 Ohio Rev. Code § 1509.074. Ohio defines “horizontal well” as: “a well that is drilled for the production of oil or gas in which the wellbore reaches a horizontal or near horizontal position in the Point Pleasant, Utica, or Marcellus formation and the well is stimulated.” Ohio Rev. Code § 1509.01(GG).

169 Ohio Admin. Code 3701:1-43-01(H).

170 Okla. Admin. Code § 165:10-7-16(e).

171 25 Pa. Code § 78a.61; 25 Pa. Code § 78a.62.

172 16 Tex. Admin. Code 4.614(c).

173 W. Va. Code §22-6A-8(g)(2).

174 055.0001.4 Wyo. Code R. § (1)(ii).

175 Alaska Department of Environmental Conservation, Authorization to Discharge Under the Alaska Pollutant Discharge Elimination System for General Permit AKG332000—Facilities Related to Oil and Gas Exploration, Production, and Development in the North Slope Borough, March 1, 2017, https://dec.alaska.gov/water/wastewater/oil-gas.

176 California State Water Resources Control Board, “Water Quality in Areas of Oil and Gas Production - Oil Field Produced Water,” https://www.waterboards.ca.gov/water_issues/programs/groundwater/sb4/oil_field_produced/ (accessed May 17, 2021).

177 2 Colo. Code Regs § 404-1(905)(c)(2)(D); 5 Colo. Code Regs § 1002-31.11(2).

178 La. Admin. Code 43 XIX.303.E.

179 N.D. Admin. Code 43-02-03-19.2 (stating that “all waste material associated with exploration or production of oil and gas must be properly disposed of in an authorized facility in accord with all applicable local, state, and federal laws and regulations”).

180 Ohio Rev. Code § 1509.22(C)(1)(d). At least one pretreatment facility discharges treated oil and gas waste to surface waters through a publicly owned treatment works (POTW). Neither the pretreatment facility nor the POTW have terms for radioactivity monitoring. See Patriot Water Treatment et al. v. Korleski et al., ERAC Nos. 156477; 156588; 786501; 786589, July 2012, https://vindy.media.clients.ellingtoncms.com/news/documents/2012/07/05/Patriot_Water_Treatment_LLC_and_City_of_Warren_Decision_.pdf.

181 Okla. Admin. Code § 165:10-7-18.

182 25 Pa. Code §78a.60; 25 Pa. Code § 93.7.

183 16 Tex. Admin. Code 4.611.

184 30 Tex. Admin. Code 307.4(c).

185 W. Va. CSR § 47-2-8.26; W. Va. CSR §47-2-8.26.1 (in Appendix E, Table 1).

186 020-0011-2 Wyo. Code R. Appendix H. See also Wagner "Permitting Treatment Facilities."

187 020-0011-1 Wyo. Code R. § 22.

188 Alaska Admin. Code tit. 20 § 25.252 (articulating no radioactivity or NORM-specific requirements).

189 Cal. Code Regs tit. 14 § 1724.7(a)(3)(H). Cal. Code Regs. tit. 14 § 1724.7.2.

190 2 Colo. Code Regs § 404-1(803)(g)(5)(C), 2 Colo. Code Regs § 404-1(909)(j)(1)(K).

191 La. Admin. Code 43:XIX.405(B)(5)(d) (requiring "qualitative and quantitative analysis of representative sample of water to be injected" but not specifying any NORM requirements). See also: Louisiana Department of Natural Resources, Office of Conservation, "Form UIC-10-A, Annual Disposal /Injection Well Monitoring," http://www.dnr.louisiana.gov/assets/docs/conservation/documents/UIC10A.pdf (accessed May 6, 2021) (requiring reports of "type of fluids injected during reporting cycle," including NORM).

192 N.M. Code R. § 19.15.26.8.E. See also New Mexico Department of Energy, Minerals, and Natural Resources, Oil Conservation Division, "Form C-108: Application for Authorization to Inject," June 10, 2003, http://www.emnrd.state.nm.us/OCD/documents/C-10820030610.pdf, (requiring "appropriate analysis of injection fluid" but not providing NORM-specific criteria).

193 N.D. Admin. Code 43-02-05-04(1)(p) (applicant for permit must include "quantitative analysis from a state-certified laboratory of a representative sample of water to be injected," but there are no NORM-specific requirements).

194 Ohio Admin. Code 1501:9-3.

195 Okla. Admin. Code § 165:10-5-5(b)(5)(D).

196 See 40 CFR §§ 144.51(j)(2); 146.23(b)-(c). EPA's permit applications indicate that an applicant must include "analysis of the chemical and physical characteristics of the injection fluid," which at a minimum "should include pH, specific gravity, TDS, and conductivity." See EPA, "Preparing and Submitting a Permit Application, 2017," 9, https://cdx.epa.gov/FAQ/ViewDocument?documentNumber=nSjGUb0gwOY%3D.

197 16 Tex. Admin. Code § 4.617(c).

198 16 Tex. Admin. Code § 4.614(f).

199 See, e.g., W. Va. CSR § 47-13-9 (articulating no specific criteria on radioactivity for Class 2 injection wells).

200 West Virginia Department of Environmental Protection, "Underground Injection Control (UIC) Permit Application Package, Class 2 and 3," 2014, https://dep.wv.gov/oil-and-gas/GI/Forms/Documents/UIC%20APPLICATION%20PACKAGE%2006-25-2014.pdf.

201 055-0001-4 Wyo. Code R. § 5.c.ix (requiring unspecified "standard laboratory analyses of the water to be disposed").

202 E. L. Rowan et al., "Radium Content of Oil- and Gas-Field Produced Waters in the Northern Appalachian Basin (USA): Summary and Discussion of Data," US Geological Survey Scientific Investigations Report 5135.2011, 2011, 31, https://pubs.usgs.gov/sir/2011/5135/pdf/sir2011-5135.pdf.

203 Lauer, Harkness, and Vengosh, "Brine Spills Associated With Unconventional Oil Development in North Dakota." See also Avner Vengosh et al., "A Critical Review of the Risks to Water Resources From Unconventional Shale Gas Development and Hydraulic Fracturing in the United States," *Environmental Science & Technology* 48, no. 15 (2014): 8334-48, https://sites.nicholas.duke.edu/avnervengosh/files/2011/08/EST-Review-on-hydraulic-fracturing.pdf.