# **ARTICLE: REGULATION OF RADIOACTIVE FRACKING WASTE**

Winter, 2018

**Reporter**

19 Vt. J. Envtl. L. 1 \*

**Length:** 10026 words

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This study was supported by the Temple University Center for Health Law, Policy & Practice and the Robert Wood Johnson Foundation Policy Surveillance Program. Preliminary results of this paper were presented as a poster at the 2016 American Public Health Annual Meeting and as a poster at the 2017 CUNY School of Public Health Research Day; the authors thank conference participants for comments on the posters. The authors also thank our team of researchers at Hunter College for assistance in coding: Emily Austerberry, Mustafa Ali, Emilio Cintron, Adam Hess, Hailu Tedia, and Henry Akinleye.

**Text**

**[\*3]** INTRODUCTION

In 2015, producers in the United States extracted natural gas from shale at record totals. The U.S. Energy Information Administration (EIA) forecasts an increase in natural gas production. [[1]](#footnote-2)1 Five states account for 65% of total dry, natural gas production as of 2015: Texas (26%), Pennsylvania (18%), Oklahoma (9%), Wyoming (6%), and Louisiana (6%). [[2]](#footnote-3)2 The dramatic increase in natural gas production is the product of new technology developed under the Carter Administration during the 1970s' energy crisis. [[3]](#footnote-4)3 By combining high-volume hydraulic fracturing (HVHF) [[4]](#footnote-5)4 with horizontal drilling, [[5]](#footnote-6)5 industry can tap ***oil*** and gas reserves trapped in shale using new technologies. [[6]](#footnote-7)6

The ***oil*** industry knew about the vast natural gas trapped in shale formations since ***oil*** and gas was discovered in Fredonia, New York, in 1821. [[7]](#footnote-8)7 In the late 1940s, hydraulic fracturing techniques were employed for the first time to stimulate ***oil*** and gas wells; however, more advanced technologies of horizontal drilling were employed decades later to facilitate lower costs and efficiency. [[8]](#footnote-9)8 Unconventional technology now allows what had been a nuisance gas to be drilled as an abundant energy resource. [[9]](#footnote-10)9 **[\*4]** Larger volumes of ***oil*** and gas are now developed in areas that were once impossible to access. [[10]](#footnote-11)10

With improved technologies exploiting the full potential of shale formations, there has been a sharp rise in drilling in areas that historically had little or no ***oil*** and gas development. [[11]](#footnote-12)11 Many of these new drill sites are in areas close to homes. [[12]](#footnote-13)12 The drilling increase has led to concern about worker and public exposure to naturally occurring radioactive materials (NORM) and technologically enhanced naturally occurring radioactive materials (TENORM). [[13]](#footnote-14)13 These wastes can contain the radioactive isotopes radium-226 (Ra-226) and radium-228 (Ra-228), which decay further into radon (Rn). [[14]](#footnote-15)14 Exposure to radon, a form of NORM, is the leading cause of lung cancer in the United States, after smoking. [[15]](#footnote-16)15 An important study regarding the Pennsylvanian portion of the Marcellus Shale suggests ***oil*** and gas extraction techniques, including hydraulic fracturing, correlate with elevated radon levels in drilling areas. [[16]](#footnote-17)16 Concern for human health due to increased seismic activity, [[17]](#footnote-18)17 along with air, [[18]](#footnote-19)18 water, [[19]](#footnote-20)19 light, [[20]](#footnote-21)20 and noise **[\*5]** pollution, [[21]](#footnote-22)21 has led some states to draft new policies. These policies add protective measures in the form of laws, regulations, and guidance documents for a variety of identified perils, including radiation exposure. [[22]](#footnote-23)22 A growing number of states with ***oil*** and gas development created standards for the disposal of NORM and TENORM wastes. [[23]](#footnote-24)23 Given the precipitous rise of ***oil*** and gas extraction from shale in the past decade, states must evaluate measures to determine whether they need further worker and public protections. Federal regulatory policies set a 10% limit on the occupational whole-body dose that workers involved in these operations rarely exceed. [[24]](#footnote-25)24 While many states impose general radiation provisions, some ***oil*** and gas states deem such provisions insufficient. Instead, those **[\*6]** states developed provisions specifically impacting ***oil*** and gas operations for the same reason that states developed provisions specific to medical use of radiation. [[25]](#footnote-26)25

This article explores and evaluates how states handle and regulate the disposal of NORM and TENORM wastes from unconventional ***oil*** and gas operations and determines the most protective practices to reduce radiological health effects. The study concludes that although some states are regulating NORM and TENORM, other states may be inadequately addressing these wastes. Multiple agencies having concurrent jurisdiction to handle waste further complicate the issue. Clearer guidance, laws, and regulations may be needed to facilitate safety and health measures in states where inadequacies could potentially harm humans, animals, and the environment.

I. GENERATING TENORM WASTE IN ***OIL*** AND GAS PRODUCTION

***Oil*** and natural gas trapped in deep, porous rock or reservoirs can move under natural pressure to the surface during conventional drilling; however, impermeable rocks, such as shale, hinder the natural flow of ***oil*** and gas. [[26]](#footnote-27)26 Hydraulic fracturing can release the trapped methane by injecting fluids containing pressurized water, sand, and chemicals to create and maintain fractures, increase permeability, and extract ***oil*** or gas. [[27]](#footnote-28)27 Once injected into the well, the fracturing fluid returns to the surface as flowback and produced water containing NORM or TENORM. [[28]](#footnote-29)28

Produced water is a mixture of both organic and inorganic materials. [[29]](#footnote-30)29 Radiation exposure occurs through the co-precipitation of radioactive NORM, such as radium and barium. [[30]](#footnote-31)30 Water and fracturing fluids surfacing during the flowback process can contain a wide range of NORM and TENORM contaminants, potentially harming water quality. [[31]](#footnote-32)31 In addition, radon-222 gas (Rn-222) can follow the processing and distribution systems, elevating the amounts of lead-210 (Pb-210) on the downstream equipment. **[\*7]** The co-precipitation of radium isotopes with other minerals in produced water and flowback accumulate in the pipelines forming scales and sludges that contain higher radioactivity concentrations. [[32]](#footnote-33)32 These radioactive materials containing radium and other progenies can be found in pipeline scrapings, sludge accumulating in tank bottoms, flowback, produced sands, and produced waters. [[33]](#footnote-34)33 A recent study reported radium concentrations of scales and sludge amounting to 94,500 picocuries per gram (pCi/g) and 59,265 pCi/g for Ra-226 and Ra-228, respectively. [[34]](#footnote-35)34 Other studies evaluating radium concentrations found median levels of 5,490 pCi/g and 1,727 pCi/g in the New York and Pennsylvania Marcellus Shale, respectively. [[35]](#footnote-36)35

Flowback and produced water contain high concentrations of brines and dissolved chemicals, with the salt content sometimes reaching very high concentrations. [[36]](#footnote-37)36 While radium's parent isotopes uranium-238 (U-238) and thorium-232 (Th-232) are insoluble, radium is highly soluble in brines and can be effectively mobilized into the formation water. [[37]](#footnote-38)37 As a result, flowback and produced water contains Ra-226, Ra-228, and their decay products. They subsequently find their way into various forms of NORM and TENORM waste, with concentrations reported from a few picocuries per gram to thousands of picocuries per gram. [[38]](#footnote-39)38 For this reason, radium and radon are far more problematic than their parent NORM isotopes due to their solubility in water and tendency to concentrate as the salinity increases. [[39]](#footnote-40)39

**[\*8]** Unlike flowback [[40]](#footnote-41)40 and produced waters, [[41]](#footnote-42)41 drill cuttings surfacing during ***oil*** and gas development usually contain NORM. [[42]](#footnote-43)42 Chemically, radium behaves in a manner similar to calcium and can bioaccumulate in plants and animals that make up the human food chain. [[43]](#footnote-44)43 Drilling cuts, produced water, and other debris from the fracturing process contain isotopes of radium; although, quantities and potential radiation hazards vary depending on exposure pathways.

Radium and radon can also surface as natural gas seeps out of the well. [[44]](#footnote-45)44 In contrast to Ra-226 and Ra-228, Rn-222 has a significantly shorter half-life of less than four days. [[45]](#footnote-46)45 Since Rn-222 surfaces with natural gas and disperses into the atmosphere upon release, Rn-222 poses less risk than **[\*9]** TENORM waste, but poses a significant threat to indoor air levels in homes. [[46]](#footnote-47)46

II. POTENTIAL ENVIRONMENTAL AND HEALTH RISKS FROM TENORM WASTE

According to the Agency for Toxic Substances Disease Registry (ATSDR), prolonged exposure to high levels of gamma radiation emitted by radium may cause adverse health effects, such as anemia, cataracts, fractured teeth, cancer, and death. [[47]](#footnote-48)47 The Environmental Protection Agency's (EPA) drinking-water limit for Ra-226 and Ra-228 is 5 picocuries per liter (5 pCi/L). [[48]](#footnote-49)48 EPA's soil-concentration limit for radium-226 in uranium and thorium mill tailings is 5 pCi/g in the first 15 centimeters of soil and 15 pCi/g in deeper soil. [[49]](#footnote-50)49 State regulations often adhere to exemption limits for Ra-226 and/or Ra-228, no matter the industry. [[50]](#footnote-51)50 Radium decaying into radon establishes another long-term health risk. [[51]](#footnote-52)51

Both radon and radium pose documented health risks. [[52]](#footnote-53)52 Radon is the second leading cause of lung cancer, and some evidence suggests it may cause other cancers such as leukemia. [[53]](#footnote-54)53 Other studies report incidences of lymphoma, bone cancer, and leukemia from drinking radium-contaminated water. [[54]](#footnote-55)54 Radium can bioaccumulate in a number of species where it can substitute for calcium in bones, although the evidence is much more limited in people. [[55]](#footnote-56)55 For radon, the EPA recommends an action level of 4 pCi/L of **[\*10]** air, but cautions that health effects are seen with exposures of less than 4 pCi/L. [[56]](#footnote-57)56 As more studies evaluate exposure and outcomes, the potential for adverse effects of radon becomes more prevalent. Thus, if areas that extract shale gas see a rise in outdoor/indoor radon levels and radium levels in TENORM waste--as indicated in one study conducted by researchers from Johns Hopkins in Pennsylvania [[57]](#footnote-58)57--those areas should take more protective measures to protect the public.

Flowback and produced water, if not treated, may also lead to elevated levels of total dissolved solids (TDS), salts, and hazardous chemicals containing NORM. [[58]](#footnote-59)58 While Ra-226 and Ra-228 are most often associated with TENORM and NORM, other radionuclides in the U-238 and Th-232 decay series are projected to increase levels of radioactivity. Some propose that radioactivity is underestimated in flowback and produced water. [[59]](#footnote-60)59 Wastewater storage impoundments (also called pits and ponds) are commonly lined with non-leaking, plastic sheeting. [[60]](#footnote-61)60 Despite such safeguards, the potential for leakage threatens the environment and public health in weather events and other emergencies. Leaks from mechanical failures could contaminate groundwater, soil, and air. Secondary potential exposure pathways from ingesting agricultural products that contain TENORM exist, but remain mostly unstudied. [[61]](#footnote-62)61 Other reports suggest the movement of chemicals leading to migration and concentrated NORM radionuclide levels cause pollution of aquifers from shale gas extraction techniques. [[62]](#footnote-63)62

Removal processes, involving deposited scales in the pipes, produce radioactive waste and pose important occupational radiation hazards to $=P**[\*11]** workers through external bodily exposure and inhalation of radioactive dusts. [[63]](#footnote-64)63 As such, TENORM causes the greatest risk to workers involved in the cleaning and removal of these scales and in decontamination processes of equipment. [[64]](#footnote-65)64 Risks exist for workers on drilling sites, maintenance workers who dismantle ***oil*** and gas equipment, and workers who recycle contaminated pipes and equipment. [[65]](#footnote-66)65 A North Dakota Department of Health study routinely monitored various activities from unconventional ***oil*** and gas operations. This included: mixing of hydraulic fracturing fluids, [[66]](#footnote-67)66 sludge treatment, pipe cleaning, and hauling of TENORM; finding 2.2 millirems/year, 30 millirems/year, 130 millirems/year, and 20 respectively. [[67]](#footnote-68)67

In addition, contaminated soil resulting from decontamination operations and other removal processes may expose the public to radiation. [[68]](#footnote-69)68 Other routes of exposure include direct gamma radiation, **[\*12]** inhalation of dusts, ingestion of contaminated water, and ingestion of contaminated food. [[69]](#footnote-70)69 Additionally, North Dakota's Department of Health found routine and accidental exposures; for members of the public adjacent to operating landfills, exposure was more than 0.024 millirems/year with an average exposure time of 8,760 hours/year. [[70]](#footnote-71)70

A study that compared radioactivity and dissolved solids in sediments, both up and downstream of a Pennsylvania wastewater treatment facility, found a 90% reduction in radioactivity in the effluent. [[71]](#footnote-72)71 Most of the NORM radioactive constituents accumulated in sludges and disposed of in landfills exceeded federal limits, thus requiring careful monitoring for TENORM in these landfills. [[72]](#footnote-73)72 This study highlights an important concern that the bioaccumulation of radium potentially increases public exposure to radiation.

A recent Pennsylvania case study of an abandoned mine reported drainage to be the most significant potential environmental problem impacting water quality. [[73]](#footnote-74)73 Despite the fact the contaminated water can be reused for shale gas extraction, with both environmental and economic benefit, the possibility of radium precipitating and finding its way into municipal waste raises an important challenge. [[74]](#footnote-75)74 Disposal of potential radium-bearing materials from TENORM waste in municipal solid waste landfills can also release radon into the atmosphere and cause a public health concern. [[75]](#footnote-76)75

Radioactive waste resulting from increased unconventional ***oil*** and gas drilling operations raises concern that workers and the public are not adequately guarded against possible exposure, with the latter exposed to more acute levels of ionizing radiation. Additionally, TENORM waste may contaminate well sites and subsequently spread to nearby areas through wind and water. [[76]](#footnote-77)76 Despite concerns of radiological risks to workers, the public, and the environment, different studies suggest the risk posed by **[\*13]** TENORM waste from ***oil*** and gas production is minimal. [[77]](#footnote-78)77 In a recent report by the Pennsylvania Department of Environmental Protection (DEP), officials concluded that there is currently little or limited potential for radiation exposure to workers and the public. [[78]](#footnote-79)78 The report further indicated potential for environmental and health impacts from specific exposure pathways, such as radium spills from ***oil*** and gas fluids during transport and storage; filter cakes with elevated TENORM from treatment of ***oil*** and gas waste; and the use of radium containing brines for dust suppression and road stabilization. [[79]](#footnote-80)79 However, the Pennsylvania DEP report underlines the need to develop appropriate safety measures for worker protection, set limits for TENORM waste, implement policies for cleanup of radioactive spills, and review protocols for long-term TENORM waste disposal. [[80]](#footnote-81)80

In contrast, a recent Johns Hopkins study evaluated predictors of indoor air concentrations by investigating whether increases in radon levels were linked to unconventional drilling. They found an increase in drilling of unconventional wells that corresponded with an upward trend in radon levels in the basements of Pennsylvania homes. [[81]](#footnote-82)81 The rising concern surrounding increased TENORM necessitates policies and regulations that coincide with the magnitude of the potential public health and environmental risks.

III. DISPOSAL OPTIONS FOR TENORM AND NORM

Safe and economical disposal methods need to be developed with the increased concentration of NORM and TENORM wastes, which include contaminated equipment, scale, sludge, drill cuttings, and produced water. TENORM may be concentrated because of:

(1) temperature and pressure changes during ***oil*** and gas production,

(2) 226Ra and 228Ra in produced waters reacting with barium sulfate (BaSO4) to form a scale in well tubulars and surface equipment,

**[\*14]** (3) 226Ra and 228Ra occurring in sludge that accumulates in pits and tanks, and

(4) NORM occurring as radon (Rn) gas in the natural gas stream. [[82]](#footnote-83)82

Historically, disposal options for ***oil*** and gas wastes are limited. These options include (1) injection or re-injection into regulated Class II disposal wells or plugged and abandoned wells; [[83]](#footnote-84)83 (2) discharge of waste into surface waters; [[84]](#footnote-85)84 (3) discharge in land via land spreading, burial, deposit in abandoned mines or tunnels, landfill dumping, and in open pits/ponds; [[85]](#footnote-86)85 (4) equipment smelting without decontamination followed by recycling of the metal and disposal of the slag; [[86]](#footnote-87)86 (5) minimization techniques including recent technologies such as gasification, oxidation-reduction-reaction chemicals, solid and fluid separation, and bioreactor cells; [[87]](#footnote-88)87 and (6) salt dome disposal where TENORM wastes are injected and placed into old-abandoned-underground salt dome formations. [[88]](#footnote-89)88

The means of disposal is often dependent on the type of waste generated. For instance, flowback and produced water brought to the surface is often collected, first stored in on-site impoundments or tanks that are often lined with plastic sheeting to prevent leakage. [[89]](#footnote-90)89 Later, flowback **[\*15]** and produced water must be removed from the drill site and disposed of or recycled. Removal typically occurs through transport to a wastewater treatment plant, injection into underground wells, or re-purposing for non-***oil*** and gas use such as watering of agricultural crops or de-icing. [[90]](#footnote-91)90 After waste is sent to wastewater treatment plants, NORM or TENORM can accumulate as sludge and scale, and potentially serve as a source of long-term exposures if not removed from piping or contaminated equipment. [[91]](#footnote-92)91 Treatment of these wastewaters can, however, further concentrate the waste streams containing radium. [[92]](#footnote-93)92 In fact, researchers in Pennsylvania discovered treatment of these wastewaters has increased radioactive concentrations in surface waters. [[93]](#footnote-94)93

The use of TENORM waste as a road de-ice or dust suppressant, using drilling cuttings in road maintenance, and spreading liquids or sludge on fields, ultimately leading to additional radiological exposures is a controversial disposal option. [[94]](#footnote-95)94 Consequently, some states now prohibit the disposal of radium-bearing NORM waste on public and private roads due to unnecessary radiation exposure. [[95]](#footnote-96)95

Other disposal options vary depending on the type of waste generated. Radium-bearing wastes, such as drill cuttings, scale, sludge, and muds may be disposed of in open pits or sent to solid waste landfills, which exposes workers and residents near these storage sites. [[96]](#footnote-97)96

If certain exemption limits mandate action, then the radium content of scale and sludge in the injected and re-injected water is often not regulated **[\*16]** the same way as radium-bearing scale and sludge. [[97]](#footnote-98)97 All options of TENORM waste disposal can cause potential radiological risk due to radium and radon emissions. [[98]](#footnote-99)98 For instance, some samples have eight times the beta radiation than is set by EPA regulatory limits. [[99]](#footnote-100)99

The number of lawsuits from TENORM exposure is on the rise. [[100]](#footnote-101)100 As recently as 2014, the Fifth Circuit Court of Appeals reversed the dismissal of claims by the survivors of deceased pipe yard workers on oilfields. The survivors claimed that exposure to TENORM bearing wastes led to a number of diseases, adverse health conditions, and death. [[101]](#footnote-102)101 The link between TENORM exposure and specific health conditions was originally difficult to prove due to many of these conditions appearing later in life. [[102]](#footnote-103)102 Additionally, exposure to low-level irradiation has not been proven to cause the cancer. [[103]](#footnote-104)103

IV. FEDERAL OVERSIGHT OF NORM AND TENORM

The natural environment contains background radiation of various concentrations, which makes regulating difficult. [[104]](#footnote-105)104 There is currently no national regulatory policy or an established cut-off for safe radiation levels. To help guide regulatory discretion, the Conference of Radiation Control Program Directors (CRCPD) put forth "Suggested State Regulations for the Control of Radiation (SSRCRs) for NORM and TENORM." [[105]](#footnote-106)105 The CRCPD has no legal authority over the regulation of TENORM or NORM, but some states chose to adopt these regulations, such as Ohio, Mississippi, and Virginia. [[106]](#footnote-107)106 NORM-bearing wastes are not generally regulated under **[\*17]** federal guidelines, but may be regulated under the U.S. Department of Transportation if the wastes are in excess of 2,000 pCi/g. [[107]](#footnote-108)107

The Atomic Energy Act of 1954 governs the operations of nuclear facilities and related activities; however, TENORM containing less than 0.05% uranium or thorium by weight, or any combination thereof, is not subject to regulatory control. [[108]](#footnote-109)108 The U.S. Nuclear Regulatory Commission (NRC) has authority to regulate disposal of low-level radioactive waste. [[109]](#footnote-110)109 However, TENORM is not governed by the Low Level Radioactive Waste Policy Act, which defines low-level radioactive waste (LLW) as material that: (i) is not a high-level radioactive waste, spent nuclear fuel, or byproduct material; and (ii) has been classified by the NRC as a LLW. [[110]](#footnote-111)110

TENORM wastes associated with ***oil*** and gas exploration and production may be categorized as special wastes and exempt from regulations under the Resource Conservation and Recovery Act's (RCRA) Subtitle C. [[111]](#footnote-112)111 Federal regulatory exemptions for ***oil*** and gas depends on how the material was used or generated as waste. For example, if waste comes to the surface during exploration and production operations or generated by contact with the ***oil*** and gas production stream during the removal of produced water or other contaminants from the product, then the waste is exempt from Subtitle C as hazardous waste. [[112]](#footnote-113)112 If, however, landfill sites created for chemically hazardous wastes under RCRA are used for TENORM waste disposal, then the wastes are subject to RCRA regulation. [[113]](#footnote-114)113 Also, under provisions of the Safe Drinking Water Act, EPA regulates certain radioactive elements regarding their total radioactivity concentration of uranium, radium-226, and radium-228. [[114]](#footnote-115)114

**[\*18]** American National Standards Institute and Health Physics Society created ANSI/HPS Standard N13.53-2009 [[115]](#footnote-116)115 that established consensus standards for disposal of TENORM wastes in solid or hazardous waste facilities. Based on these standards, the Association of State & Territorial Solid Waste Management Officials (ASTSWMO) set forth guidelines for TENORM waste disposal in solid waste facilities recommending a 25 millirems/year limit for exposure to the public. [[116]](#footnote-117)116

The Occupational Safety and Health Administration (OSHA) promulgated rules specific to occupational exposure to ionizing radiation, which may or may not apply to shale gas extraction. [[117]](#footnote-118)117 OSHA governs general regulations for TENORM because of its role in advocating for worker's health and safety. [[118]](#footnote-119)118 Seventeen states developed clearance levels and regulations for managing these materials under ***oil*** and gas provisions or waste disposal provisions. [[119]](#footnote-120)119 Per the U.S. EIA, at least 21 states are producing 50 million cubic feet of natural gas or ***oil*** annually that are contributing to significant sources of NORM and TENORM. [[120]](#footnote-121)120 Five states have provisions protecting workers that are expressly applied to ***oil*** and gas workers, while only three states include protections for the public. [[121]](#footnote-122)121

Through radiation control measures, it is the states' responsibility to regulate TENORM. States protect ***oil*** and gas and other downstream operations that are exposed to TENORM differently. [[122]](#footnote-123)122 Thus, regulations for NORM and TENORM remain inconsistent across the country. [[123]](#footnote-124)123

V. NORM & TENORM REGULATION IN THE STATES

**[\*19]** The number of active ***oil*** and gas wells in the U.S. has exponentially grown in the past decade because of technological advances that allow access to large shale ***oil*** and gas reserves. There are more than 1.7 million ***oil*** and gas wells drilled across 35 of the 50 states (70%) in the U.S. Although density varies widely, an estimated 1,673 out of 3,144 (53%) U.S. counties now have an ***oil*** or gas well. [[124]](#footnote-125)124 The density of drilled wells per state ranges from 57 in Maryland to about 291,996 in Texas. [[125]](#footnote-126)125 One hundred thirty-five counties have a single ***oil*** or gas well. [[126]](#footnote-127)126 Texas has the greatest collective number of wells. [[127]](#footnote-128)127 ***Kern*** County, California, has the most active wells in the U.S. with 77,497 ***oil*** and gas wells. [[128]](#footnote-129)128

Although EPA issued a general guidance memo in 2003, [[129]](#footnote-130)129 regulation of TENORM and NORM is left to each ***oil*** and gas state. [[130]](#footnote-131)130 Thus, many states have either chosen to include regulation of TENORM or NORM under general radiation provisions or to adopt regulations under ***oil*** and gas provisions. [[131]](#footnote-132)131 Table 1 presents a summary of state approaches to regulating NORM and TENORM in the ***oil*** and gas industry presented by level of state activity, as of 2015. [[132]](#footnote-133)132 Table 1 includes the authority where each state developed the protective measures, whether it be laws, regulations, guidance, or case-by-case permitting. [[133]](#footnote-134)133**[\*20]**

|  |  |  |  |  | ***Oil* and** |
| --- | --- | --- | --- | --- | --- |
|  |  |  |  | **General** | **Gas Laws** |
|  |  | **Number** |  | **Radiation** | **for** |
|  | **States** | **of Wells** | **Agreement** | **Provisions** | **TENORM** |
| **State** | **Producing** | **in State** | **State** [[134]](#footnote-135)134 | **for** | **or NORM** |
|  | ***Oil* & Gas** | **(as of** |  | **TENORM or** | **Laws** |
|  |  | **2015)** |  | **or NORM** | **for** |
|  |  |  |  |  | **Disposal** |
| TX |  | 291,996 | \*[checkmark] | NORM\* | [checkmark] |
|  |  |  |  |  |  |
| KS |  | 252,097 | \*[checkmark] |  | [checkmark] |
|  |  |  |  |  |  |
| OK |  | 206,373 | \*[checkmark] |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  | [checkmark] |
| PA |  | 136,036 | \*[checkmark] |  |  |
|  |  |  |  |  |  |
| WV |  | 109,747 |  | TENORM |  |
|  |  |  |  |  |  |
| CA |  | 105,037 | \*[checkmark] |  | [checkmark] |
|  |  |  |  |  |  |
| CO |  | 72,313 | [checkmark] | Both | [checkmark] |
|  |  |  |  |  |  |
| IL |  | 69,222 | \*[checkmark] |  | [checkmark] |
|  |  |  |  |  |  |
| WY |  | 66,298 |  |  | [checkmark] |
|  |  |  |  |  |  |
| LA |  | 64,710 | \*[checkmark] | Both | [checkmark] |
|  |  |  |  |  |  |
| NM |  | 60,943 | [checkmark] | NORM\* | [checkmark] |

**[\*21]**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  |  | \* |  |  |
|  |  |  |  |  |  |
| KY | 1[checkmark] | 32,483 | \*[checkmark] |  | [checkmark] |
|  |  |  |  |  |  |
| UT | 1[checkmark] | 27,352 | \* |  |  |
|  |  |  |  |  |  |
| NY | 1[checkmark] | 24,435 | \*[checkmark] | NORM\* |  |
|  |  |  |  |  |  |
| MT | 1[checkmark] | 19,928 |  |  | [checkmark] |
|  |  |  |  |  |  |
| MI | 1[checkmark] | 19,821 |  |  |  |
|  |  |  |  |  |  |
| AR |  | 18,645 |  | NORM |  |
|  |  |  |  |  |  |
| ND | 1[checkmark] | 17,931 | \*[checkmark] | TENORM | [checkmark] |
|  |  |  |  |  |  |
| TN | 1[checkmark] | 15,814 | \* |  |  |
|  |  |  |  |  |  |
| VA | 1[checkmark] | 11,850 | \*[checkmark] | Both |  |
|  |  |  |  |  |  |
| AL |  | 8,017 |  |  |  |
|  |  |  |  |  |  |
| MS | 1[checkmark] | 7,897 | \*[checkmark] | Both | [checkmark] |
|  |  |  |  |  |  |
| IN | 1[checkmark] | 7,672 |  |  |  |
|  |  |  |  |  |  |
| MO |  | 6,590 |  |  |  |
| AK |  | 5,643 |  |  |  |
|  |  |  |  |  |  |
| NE | 1[checkmark] | 3,140 | \*[checkmark] | TENORM |  |
|  |  |  |  |  |  |
| OH | 1[checkmark] | 1,916 | \*[checkmark] | both | [checkmark] |

**[\*22]**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| WA | 0[checkmark] | 721 | \*[checkmark] |  | [checkmark] |
|  |  |  |  |  |  |
| SD | 1[checkmark] | 587 |  |  | [checkmark] |
|  |  |  |  |  |  |
| OR | 1[checkmark] | 522 | \*[checkmark] | NORM |  |
|  |  |  |  |  |  |
| AZ | 1[checkmark] | 369 |  |  |  |
|  |  |  |  |  |  |
| NV | 1[checkmark] | 250 | \*[checkmark] |  |  |
|  |  |  |  |  |  |
| ID |  | 152 | \*[checkmark] |  |  |
|  |  |  |  |  |  |
| FL | 1[checkmark] | 123 | \*[checkmark] |  |  |
|  |  |  |  |  |  |
| MD | 1[checkmark] | 57 | \*[checkmark] |  |  |
|  |  |  |  |  |  |
| CT |  | 0 |  |  |  |
| DC |  | 0 |  |  |  |
| DE |  | 0 |  |  |  |
|  |  |  |  |  |  |
| GA |  | 0 | \*[checkmark] | Both |  |
|  |  |  |  |  |  |
| HI |  | 0 |  |  |  |
| IA |  | 0 |  |  |  |
|  |  |  |  |  |  |
| MA |  | 0 | \*[checkmark] | TENORM |  |
|  |  |  |  |  |  |
| ME |  | 0 | \*[checkmark] |  |  |
|  |  |  |  |  |  |
| MN |  | 0 | \*[checkmark] |  |  |

**[\*23]**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| NC |  | 0 | [checkmark] |  |  |
|  |  |  |  |  |  |
| RI |  | 0 | \* [checkmark] |  |  |
|  |  |  |  |  |  |
| SC |  | 0 | \* [checkmark] | Both |  |
|  |  |  |  |  |  |
| NH |  | 0 | \* [checkmark] |  |  |
|  |  |  |  |  |  |
| NJ |  | 0 | \* [checkmark] | Both |  |
|  |  |  |  |  |  |
| VT |  | 0 |  |  |  |
| \*NORM is used interchangeable to TENORM | | | | | |

Table 2 summarizes the types of protections included in state ***oil*** and gas laws and regulations.

| ***Oil* & Gas Regulations** | | | | |
| --- | --- | --- | --- | --- |
| **State** | **Worker** | **Public** | **Scale** | **Sludge** |
|  | **Protection** | **Protections** |  |  |
| TX | [checkmark] |  |  | [checkmark] |
|  |  |  |  |  |
| KS |  |  |  |  |
|  |  |  |  |  |
| OK |  |  |  |  |
|  |  |  |  |  |
| PA |  |  |  | [checkmark] |
|  |  |  |  |  |
| WV |  |  |  |  |

| ***Oil* & Gas Regulations** | | | |
| --- | --- | --- | --- |
| **State** | **Produced** | **Drill** | **Contaminated** |
|  | **water** | **cuttings** | **equipment** |
| TX | [checkmark] |  | [checkmark] |
|  |  |  |  |
| KS |  | [checkmark] |  |
|  |  |  |  |
| OK |  |  |  |
|  |  |  |  |
| PA |  |  | [checkmark] |
|  |  |  |  |
| WV |  |  | [checkmark] |

**[\*24]**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| CA |  |  |  |  |  |  |  |
| CO | ✓ | ✓ |  | ✓ |  |  | ✓ |
| IL |  |  |  |  |  | ✓ |  |
| WY |  |  |  | ✓ |  |  | ✓ |
| LA | ✓ |  |  | ✓ |  |  | ✓ |
| NM | ✓ | ✓ |  | ✓ | ✓ |  | ✓ |
| KY |  |  |  |  |  |  |  |
| UT |  |  |  |  |  |  |  |
| NY |  |  |  |  |  |  |  |
| MT |  |  |  |  | ✓ | ✓ | ✓ |
| MI |  |  |  |  |  |  |  |
| AR |  |  |  | ✓ |  |  | ✓ |
| ND |  |  |  | ✓ |  |  |  |
| TN |  |  |  |  |  |  |  |
| VA |  |  |  |  |  |  |  |
| AL |  |  |  |  |  |  |  |
| MS | ✓ | ✓ |  | ✓ | ✓ |  | ✓ |
| IN |  |  |  |  |  |  |  |
| MO |  |  |  |  |  |  |  |
| AK |  |  |  |  |  |  |  |

**[\*25]**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| NE |  |  |  |  |  |  |  |
| OH |  |  |  |  |  |  | [checkmark] |
| WA |  |  |  |  |  |  |  |
| SD |  |  |  |  |  |  |  |
| OR |  |  |  |  |  |  | [checkmark] |
| AZ |  |  |  |  |  |  |  |
| NV |  |  |  |  |  |  |  |
| ID |  |  |  |  |  |  |  |
| FL |  |  |  |  |  |  |  |
| MD |  |  |  |  |  |  |  |
| CT |  |  |  |  |  |  |  |
| DC |  |  |  |  |  |  |  |
| DE |  |  |  |  |  |  |  |
| GA |  |  |  |  | [checkmark] |  | [checkmark] |
| HI |  |  |  |  |  |  |  |
| IA |  |  |  |  |  |  |  |
| MA |  |  |  |  |  |  |  |
| ME |  |  |  |  |  |  | [checkmark] |
| MN |  |  |  |  |  |  |  |
| NC |  |  |  |  |  |  |  |
| RI |  |  |  |  |  |  |  |
| SC |  |  |  |  |  |  | [checkmark] |

**[\*26]**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| NH |  |  |  |  |  |  |  |
| NJ |  |  |  |  |  |  |  |
| VT |  |  |  |  |  |  |  |
| WI |  |  |  |  |  |  |  |

*A. NORM & TENORM Regulation in States with* ***Oil*** *& Gas Drilling*

Below is a state-by-state description of NORM and TENORM protections provided to ***oil*** and gas workers and the general public under respective state laws and policies.

1. Texas

Texas has a long history of ***oil*** and gas production. It also has one of the oldest and most robust ***oil*** and gas economies in the country. [[135]](#footnote-136)135 In fact, Texas was the second state in the U.S. to pass legislative measures regarding ***oil*** refineries in 1899. [[136]](#footnote-137)136 While the first sighting of ***oil*** in Texas was as far back as 1543, ***oil*** in Texas was not discovered or produced until the second half of the 19th century, and discovery and production has only increased with the advent of technologies. [[137]](#footnote-138)137 As of 2015, Texas had 291,996 ***oil*** and gas wells drilled. [[138]](#footnote-139)138 Significant drilling for natural gas occurs in all areas of the state in the five major formations. [[139]](#footnote-140)139 Due to the **[\*27]** significant amount of ***oil*** and gas production, Texas has some of the most comprehensive laws and regulations in the country. [[140]](#footnote-141)140

The Barnett Shale covers 5,000 square miles and is considered the largest onshore natural gas formation in the U.S. [[141]](#footnote-142)141 Mitchell Energy used new drilling technologies to realize the Barnett Shale's full potential. [[142]](#footnote-143)142 The Eagle Ford Shale is 50 miles wide and 400 miles long; it has been a significant source of both gas and ***oil*** production ever since Petrohawk drilled its first wells in 2008. [[143]](#footnote-144)143 Since 1993, the Granite Wash, located in the Texas Panhandle and Western Oklahoma, has produced 17.2 million barrels of ***oil*** and roughly 1.4 billion MCF of natural gas, with production only increasing in the last decade. [[144]](#footnote-145)144 The Haynesville/Bossier Shale is a geological formation that can deliver large amounts of gas, becoming one of the major sources of natural gas. [[145]](#footnote-146)145 Lastly, the Permian Basin is an ***oil*** and gas producing area located in West Texas and the adjoining area of Southeastern New Mexico. [[146]](#footnote-147)146 The Permian Basin covers an area approximately 250 miles wide and 300 miles long; it remains a significant ***oil*** producing area producing more than 270 million barrels of ***oil*** in 2010 and more than 280 million barrels in 2011. [[147]](#footnote-148)147

Texas has regulated NORM under general radiation provisions since 1999; however, the provisions are not intended to regulate the disposal of NORM from ***oil*** and gas exploration. [[148]](#footnote-149)148 Texas's long history of ***oil*** and gas production prompted the State to draft additional legislation aimed specifically at ***oil*** and gas NORM, which falls under the jurisdiction of the **[\*28]** Railroad Commission of Texas (RRC). [[149]](#footnote-150)149 While these regulations do not supersede the general radiation provisions concerning NORM, they go further to address the radioactivity in ***oil*** and gas waste that presents new challenges. [[150]](#footnote-151)150 In fact, Texas agencies have memoranda between them to "delineate areas of respective jurisdiction and to coordinate the respective responsibilities and duties of the DSHS and the RRC in the regulation of sources of radiation in accordance with Texas Health and Safety Code (HSC)." [[151]](#footnote-152)151

Texas uses the term NORM instead of TENORM, under both the general radiation provisions [[152]](#footnote-153)152 and ***oil*** and gas NORM disposal provisions. [[153]](#footnote-154)153 Texas defines NORM as "[n]aturally occurring [radioactive] materials not regulated under the AEA whose radionuclide concentrations have been increased by or as a result of human practices," which often meets the definition of TENORM. [[154]](#footnote-155)154 ***Oil*** and gas NORM waste disposal limits for Ra-226 or Ra-228 are 30 pCi/g or less or 150 pCi/g of any other NORM radionuclide, [[155]](#footnote-156)155 set forth under licensing requirements for NORM. [[156]](#footnote-157)156 Pipes and other equipment used in ***oil*** production contaminated with NORM scale or residue should not exceed 50 microroentgen/hour (μR/hr). [[157]](#footnote-158)157

The RRC further regulates the disposal of NORM-bearing wastes in ***oil*** and gas operations. [[158]](#footnote-159)158 Worker protections must be in place during the handling of NORM-bearing wastes and must adhere to provisions set out in the general licensure of NORM. [[159]](#footnote-160)159 Produced water, which is considered NORM, is exempt from the requirements of these regulations, subject to regulations involving Class II injection wells. [[160]](#footnote-161)160 Authorized disposal methods of NORM, which includes scale, sludge, and contaminated **[\*29]** equipment, are outlined and detailed. [[161]](#footnote-162)161 The following methods are included: disposal in plugged and abandoned wells, burial, land farming, disposal at a licensed facility, and deep well injection (pre-treated). [[162]](#footnote-163)162 Texas prohibits the release of NORM-bearing and TENORM-bearing wastes into surface and subsurface waters. [[163]](#footnote-164)163 In addition, Texas prohibits the disposal of NORM-bearing wastes on public or private roads. [[164]](#footnote-165)164

2. Kansas

***Oil*** was first discovered in Neodesha, Kansas, on November 28, 1892. [[165]](#footnote-166)165 Since that time, more than 350,000 wells have been drilled yielding more than five billion barrels of ***oil***. [[166]](#footnote-167)166 The first experimental hydraulic fracturing treatment in the U.S. took place in 1947 in the Hugoton Gas Field in Grant County, Kansas. [[167]](#footnote-168)167 Since that first well, 252,097 wells have been hydraulically fractured as of 2015. [[168]](#footnote-169)168

While Kansas is an agreement state, it does not have specific licensure provisions for TENORM or NORM. [[169]](#footnote-170)169 Rather, both TENORM and NORM are defined in solid waste management regulations and general radiation provisions. [[170]](#footnote-171)170 Specific to ***oil*** and gas, Kansas allows land-spreading of NORM waste up to 10 pCi/g. [[171]](#footnote-172)171 In this context, drill cuttings are considered NORM, and if the NORM level is more than the standard land-spreading must be stopped. [[172]](#footnote-173)172 Further, Kansas established certain exemptions for permit requirements for disposal "of solid waste generated by drilling ***oil*** and gas wells by land-spreading in accordance with best management **[\*30]** practices and maximum loading rates established in rules and regulations adopted by the secretary." [[173]](#footnote-174)173

Unlike Texas, the Kansas regulations do not address radioactivity of produced water, scale, sludge, or contaminated equipment. Given the rise in natural gas production, Kansas does not sufficiently address TENORM or NORM wastes.

3. Oklahoma

***Oil*** was first discovered in Oklahoma in the late 1880s, and production of ***oil*** increased until about 1967 with estimates of 14.5 billion barrels in total. [[174]](#footnote-175)174 Oklahoma remained the top ***oil***-production state in the U.S. until 1923. [[175]](#footnote-176)175 Oklahoma sits on the Caney and Woodford shale formations. As of 2015, Oklahoma is the state with the third highest number of wells in the U.S. with an estimated 206,373 wells drilled. [[176]](#footnote-177)176

In recent years, Oklahoma saw a notable rise in the number of earthquakes. [[177]](#footnote-178)177 The increase in seismic activity in Oklahoma has attracted national attention--with many calling for increased regulatory action to reduce seismic impacts on Oklahoma residents. In an effort to regulate the industry, Oklahoma has taken measures to require disclosure of chemicals used in the fracturing fluid. [[178]](#footnote-179)178 These measures require disclosure within 60 days either directly to the Chemical Disclosure Registry on FracFocus or **[\*31]** indirectly to the Oklahoma Corporation Commission. [[179]](#footnote-180)179 Companies, however, can claim exemptions if the chemical formulas are trade secrets. [[180]](#footnote-181)180 Such exemptions allow for loopholes and may be contributing to overexposures to chemicals and radioactive elements. Despite the call for increased regulatory action, the desire for increased state ***oil*** and gas regulation is not universal. Oklahoma lawmakers sought to ban communities from issuing local bans on fracking in response to the rise in earthquakes. [[181]](#footnote-182)181

Although Oklahoma is an agreement state, neither the general radiation provisions nor the ***oil*** and gas provisions expressly license TENORM or NORM. While Oklahoma is a major ***oil*** and gas producer, Oklahoma laws governing the ***oil*** and gas industry as well as general radiation provisions lack regulatory framework regarding TENORM and NORM waste.

4. Pennsylvania

Pennsylvania has 136,036 drilling wells. [[182]](#footnote-183)182 Pennsylvania also has one of the largest shale formations in the country--the Marcellus Shale. [[183]](#footnote-184)183 The Marcellus Shale is estimated to contain 10 to 100 parts per million (ppm) of uranium, whereas other areas in the U.S. average only 3 ppm. ***Oil*** and gas exploration began in the Marcellus Shale in earnest in 2003. [[184]](#footnote-185)184

**[\*32]** Pennsylvania is one of the fastest growing areas for hydraulic fracturing. Given the high uranium content of the Marcellus Shale, the potential for radiological exposure to TENORM-generated wastes during shale gas extraction is particularly problematic. [[185]](#footnote-186)185 To deal with the wastes, Pennsylvania employs a number of techniques, including treatment of flowback and produced water and subsequent release into state surface waters. [[186]](#footnote-187)186 An estimated 1,210 million gallons per day of water from lakes, rivers, and streams are withdrawn in Pennsylvania for public supply. [[187]](#footnote-188)187 Furthermore, as many as 8 million people rely on drinking water from streams alone. [[188]](#footnote-189)188

To facilitate monitoring radioactivity in waste, the Pennsylvania DEP issued a guidance document pursuant to the Pennsylvania Solid Waste Management Act, the Radiation Protection Act, and specific provisions of the Pennsylvania Administrative Code that define NORM and TENORM. [[189]](#footnote-190)189 Workers and the public are protected by general radiation provisions, but they are not expressly covered for NORM and TENORM in ***oil*** and gas operations. However, Pennsylvania does require radiation testing at landfills under the solid waste regulations, thus serving as some protection for nearby residents and workers at landfills from TENORM waste. [[190]](#footnote-191)190

In 2013, the Pennsylvania DEP conducted a study in response to the large amount of TENORM waste generated during shale gas extraction. [[191]](#footnote-192)191 The DEP study assessed worker and public exposures from TENORM waste generation, disposal, and reuse on roads as a dust suppressor or road stabilizer. [[192]](#footnote-193)192 The DEP concluded that there was little potential for harm to workers or the public from radiation exposure due to ***oil*** and gas drilling. [[193]](#footnote-194)193 **[\*33]** This study served as a check on existing ***oil*** and gas TENORM regulations and led the State to conclude that no additional protective regulation was needed. [[194]](#footnote-195)194 The study did conclude that there is potential exposure to radiation from treatment of ***oil*** and gas wastes and spills. [[195]](#footnote-196)195 Thus, the DEP should incorporate protocols during site characterization and should evaluate and implement work protections to address these concerns. [[196]](#footnote-197)196

5. West Virginia

The West Virginia portion of the Marcellus Shale has an estimated 109,747 ***oil*** and gas wells, [[197]](#footnote-198)197 including 29 wells operated in the Gauley River and New River Gorge National River. [[198]](#footnote-199)198 While West Virginia is not an agreement state, TENORM is licensed under general radiation provisions, which also include contaminated equipment. [[199]](#footnote-200)199 The exemption limit for TENORM waste is 5 pCi/g for Ra-226 and Ra-228. [[200]](#footnote-201)200 The West Virginian regulatory guidelines are consistent with many other states operating with the same number of wells.

6. California

California has an estimated 105,037 wells, [[201]](#footnote-202)201 and the industry contributes 9% to the State's GDP. [[202]](#footnote-203)202 In California, hydraulic fracturing has occurred since the 1980s. Production on many of the formations in California occurs via vertical wells into conventional ***oil*** and natural gas **[\*34]** reserves. [[203]](#footnote-204)203 While there are protection standards in place for well operations, California has not enacted legislation regarding TENORM waste generated during these operations. [[204]](#footnote-205)204 A RCRA hazardous waste facility in California, however, is permitted to take up to 1,800 pCi/g TENORM and NORM waste in the U-238, U-235, and Th-232 decay series. [[205]](#footnote-206)205

7. Colorado

Colorado has an estimated 72,313 wells. [[206]](#footnote-207)206 The first ***oil*** well was drilled in the Pierre Shale Formation in 1901, and large-scale fracking occurred in Colorado as early as 1973. [[207]](#footnote-208)207 Colorado has four shale formations within its borders: the Niobrara Shale Formation, Green River Formation, Sand Wash Basin, and Wattenberg Gas Field. [[208]](#footnote-209)208 The Wattenberg Gas Field is responsible for much of the natural gas play in Colorado, with estimates that it holds 5.2 trillion cubic feet of gas. [[209]](#footnote-210)209 As of 2014, Colorado produced **[\*35]** more than 82.8 million barrels of crude ***oil***. [[210]](#footnote-211)210 Disposal of wastes generated during ***oil*** and gas operations has gained recent attention as lawsuits aimed at enacting local bans on fracking or banning disposal of wastes in communities are filed. [[211]](#footnote-212)211

Regulated disposal of TENORM and NORM occurs in the Deer Trail Landfill in Colorado. The landfill is a RCRA Subtitle C facility accepting up to 2,000 pCi/g of TENORM or NORM waste. [[212]](#footnote-213)212 Given the large amounts of TENORM waste that is accepted at this facility, it is becoming a major acceptor of ***oil*** and gas wastes in the region. [[213]](#footnote-214)213 Overall, the regulation of radioactive material in Colorado is the responsibility of the Radiation Control Program (RCP) of the Hazardous Materials and Waste Management Division (HMWMD). The authority to regulate TENORM is found in the general provisions of the Radiation Control Act and the Colorado Rules and Regulations pertaining to radiation control, both of which define TENORM and NORM. [[214]](#footnote-215)214 Sludge, scale, and contaminated equipment are all considered TENORM under Colorado law. [[215]](#footnote-216)215

Colorado is developing final guidance pertaining to the disposal of TENORM waste that may be applicable to ***oil*** and gas operations. [[216]](#footnote-217)216 The proposed standards would restrict the disposal of Ra-226 and Ra-228 in excess of 3 pCi/g in municipal solid waste landfills and 50 pCi/g in industrial landfills. [[217]](#footnote-218)217 Guidance was originally meant to address TENORM **[\*36]** generated from the treatment of drinking water; thus, the guidance may loosely apply to TENORM generated during ***oil*** and gas operations. [[218]](#footnote-219)218 Regardless, the guidance outlines various disposal options as well as worker and public protections--serving as a basis for the development of protections. [[219]](#footnote-220)219

8. Illinois

Illinois has an estimated 69,222 wells. [[220]](#footnote-221)220 ***Oil*** and gas production first occurred in the Illinois Basin in 1853, which is the third largest in the United States. Since 1853, Illinois produced approximately four billion barrels of ***oil*** and four trillion cubic feet of natural gas. [[221]](#footnote-222)221 While production fell following World War II, increased drilling was economically possible due to advancements in drilling technologies. [[222]](#footnote-223)222 Regulations pertaining to wastes that are generated during these drilling operations are addressed to some extent in ***oil*** and gas provisions of the Hydraulic Fracturing Regulatory Act. [[223]](#footnote-224)223 The Act defines both TENORM and NORM [[224]](#footnote-225)224 and addresses drill cuttings in the drilling mud but not in terms of its radioactivity. [[225]](#footnote-226)225 Furthermore, Illinois outlines permit requirements for flowback and other fluids brought to the surface with hydraulic fracturing and specifies disposal in Class II injection wells. However, the law lacks specificity to the flowback's radioactivity. [[226]](#footnote-227)226 The State prohibits the "unlawful [] inject[ion] or discharge [of] hydraulic fracturing fluid, **[\*37]** produced water, BTEX, diesel, or petroleum distillates into fresh water (Section 1-25(c) of the Act)." [[227]](#footnote-228)227

Illinois allows for water treatment residuals and sewage treatment sludge, with total radium concentrations of 200 pCi/g or less, to be disposed of at a landfill. [[228]](#footnote-229)228 This limit is not, however, explicit to TENORM or NORM in the ***oil*** and gas industry. [[229]](#footnote-230)229 TENORM is also addressed in the compact between Illinois and Kentucky in the Central Midwest Interstate Low-Level Radioactive Waste Commission, which categorizes NORM, NARM, and TENORM as low-level radioactive waste (LLRW). [[230]](#footnote-231)230 The State limits the disposal at LLRW facilities of 2,000 pCi/g of TENORM waste and prohibits import of TENORM waste with concentrations equal to or greater than 5 pCi/g. [[231]](#footnote-232)231

9. Wyoming

Wyoming has an estimated 66,298 wells. [[232]](#footnote-233)232 Much of the activity occurs in the Powder River Basin, where 22 of the 23 counties produce natural gas. [[233]](#footnote-234)233 A recent study found that fracking waste had a negative impact on water supplies in Wyoming. [[234]](#footnote-235)234

Wyoming is a letter of intent state. [[235]](#footnote-236)235 Wyoming developed guidance for NORM and TENORM disposal under their solid and hazardous waste division, which is under the jurisdiction of the Wyoming Department of Environmental Quality. [[236]](#footnote-237)236 NORM is defined as "any waste material exceeding the greater of natural background levels found in nearest non-impacted **[\*38]** natural soils at the surface or 8 [pCi/g Ra-226] and/or decommissioned equipment from crude ***oil*** or gas operations exceeding 50 [μR/hr] emanation rate at any accessible point." [[237]](#footnote-238)237 The Wyoming guidance, where NORM wastes have not been removed, distinguishes between NORM contaminated soils, scale, sludge and tank bottoms and equipment. [[238]](#footnote-239)238 Management of NORM and TENORM is permitted in solid waste landfills if waste is less than or equal to 30 pCi/g of Ra-226 up to 20 cubic yards. [[239]](#footnote-240)239 If levels are more than 50 pCi/g then the waste must be transferred to a low-level radioactive waste facility outside of Wyoming. [[240]](#footnote-241)240 NORM equipment contaminated with less than 50 μR/hr can be recycled, and up to 20 tons may be disposed of in a State permitted solid waste disposal facility. [[241]](#footnote-242)241

10. Louisiana

Natural gas was first discovered in Louisiana in 1870. [[242]](#footnote-243)242 The first commercially operated ***oil*** wells were drilled at the turn of the 20th century. [[243]](#footnote-244)243 Louisiana passed its first legislative measure governing ***oil*** in 1906. [[244]](#footnote-245)244 The State has a long history of ***oil*** and gas production, with the State reaching an estimated 64,710 wells as of 2015. [[245]](#footnote-246)245

The Louisiana Department of Environmental Quality (LDEQ) issued regulations to deal with wastes from ***oil*** and gas operations. LDEQ accepts NORM wastes in Subtitle D landfills if the waste is less than or equal to 5 pCi/g above background levels. [[246]](#footnote-247)246 Under State regulations, NORM and aspects of TENORM are covered including those from ***oil*** and gas. [[247]](#footnote-248)247 The exemption limit for disposal is set at 5 pCi/g or less of Ra-226 or Ra-228 or **[\*39]** 150 pCi/g of any other NORM radionuclide. [[248]](#footnote-249)248 NORM-contaminated equipment is exempt if the maximum radiation exposure level does not exceed 50 μR/hr. [[249]](#footnote-250)249 "Produced waters from crude ***oil*** and natural gas production are exempt from the requirements of these regulations," but subject to regulations pertaining to water quality. [[250]](#footnote-251)250

In Louisiana, NORM disposal can occur by any of the following:

(1) by transfer of the wastes to a land disposal facility licensed by [LDEQ], or the U.S. Nuclear Regulatory Commission, an agreement state, or a licensing state;

(2) by alternate methods authorized in writing by LDEQ upon application or the department's initiative . . .;

(3) for nonhazardous oilfield waste containing NORM at concentrations not exceeding 30 [pCi/g] of radium-226 or radium-228 by transfer to a nonhazardous oilfield waste commercial facility regulated by the Department of Natural Resources [DNR] for treatment if the following are met:

a. dilution in the end product after treatment does not exceed 5 [pCi/g] above background of radium-226 or radium-228;

b. the nonhazardous oilfield waste commercial facility has a program for screening incoming shipments to ensure that the 30 [pCi/g] limit of radium-226 or radium-228 is not exceeded; and

c. the DNR approves; or

(4) for nonhazardous oilfield waste containing concentrations of NORM more than the limits in LAC 33: XV.1404.A.1, but not exceeding 200 [pCi/g] of radium-226 or radium-228 and daughter products, by treatment at nonhazardous oilfield waste commercial facilities specifically licensed by the department for such purposes. [[251]](#footnote-252)251

These regulations cover the protection of workers by referencing the protections found under the general radiation provisions. [[252]](#footnote-253)252

11. New Mexico

**[\*40]** New Mexico has an estimated 60,943 wells [[253]](#footnote-254)253 that are mostly located in the San Juan Basin. [[254]](#footnote-255)254 New Mexico also overlies part of the Permian Basin, a significant ***oil***-producing formation that produces approximately 2.4 million barrels per day. [[255]](#footnote-256)255 New Mexico, like Texas, has a detailed regulatory framework for NORM disposal (although the definition of TENORM reads akin to the way many states define NORM). [[256]](#footnote-257)256 New Mexico regulates NORM-bearing materials in the ***oil*** and gas industry and their disposal in solid waste facilities, and as such New Mexico requires testing prior to leaving the well. [[257]](#footnote-258)257 New Mexico stipulates specific disposal options for ***oil*** and gas NORM in: (1) non-retrieved flowlines and pipelines; (2) disposal of NORM at commercial or centralized surface waste management facilities; (3) disposal of NORM in plugged and abandoned wells; and (4) deep well injection of NORM from the ***oil*** and gas industry. [[258]](#footnote-259)258

The disposal limits, which are specific to ***oil*** and gas, are subject to licensure requirements set forth in the general radiation provisions. [[259]](#footnote-260)259 This makes New Mexico the only state in the U.S. to apply their general radiation standards and licensing specifically to NORM generated during ***oil*** and gas extraction, transfer, transport, storage, or disposal. [[260]](#footnote-261)260 Regulations on NORM generated in the ***oil*** and gas industry also apply to sludges and scale deposits in tubulars and equipment and to cleaning operations. [[261]](#footnote-262)261 Under § 20.3.14.1403, New Mexico sets exemption limits of "30 [pCi/g] or less of radium 226, above background, or 150 [pCi/g] or less of any other NORM radionuclide, above background, in soil, in 15 cm layers, averaged over 100 square meters"; the exemption limit for **[\*41]** contaminated equipment is 50 μR/hr; and sludges and scales are exempt if Ra-226 does not exceed 30 pCi/g. [[262]](#footnote-263)262

New Mexico sets worker protection guidelines that include limits to exposure for workers with licenses, such as "[a]ny worker engaged in an activity subject to a Specific License and who is likely to receive in one year an accumulative dose in excess of 500 mrem (5 mSv) shall be monitored." [[263]](#footnote-264)263 Protections for the general New Mexico population are set to not exceed 100 mrem (1 mSv) in a year or 2 mrem (.020 mSv) for an unrestricted area in any one hour. [[264]](#footnote-265)264

12. Kentucky

Kentucky has an estimated 32,483 wells, [[265]](#footnote-266)265 mostly in the Devonian Shale. [[266]](#footnote-267)266 Kentucky was the first state in the U.S. to become an agreement state. [[267]](#footnote-268)267 In Kentucky, TENORM is classified as low-level radioactive waste [[268]](#footnote-269)268 and is defined as "[n]aturally occurring radioactive material with a radionuclide concentration that has been increased by [or because] of human activities." [[269]](#footnote-270)269 Per the Central Midwest Interstate Low-Level Radioactive Waste Commission Compact, Kentucky laws govern the disposal of TENORM such that 2,000 pCi/g of TENORM waste may be **[\*42]** disposed of at a LLRW facility. [[270]](#footnote-271)270 For all industries, radioactive waste including NORM can be disposed of:

(1) By transfer to an authorized recipient as provided in 902 KAR 100:040, Section 12, or 902 KAR 100:022;

(2) By decay in storage;

(3) By release in an effluent within the limits in 902 KAR 100:019, Section 10;

(4) [By] treatment or disposal by incineration;

(5) [By] decay in storage; or

(6) [By] disposal at a land disposal facility licensed under 902 KAR 100:022. [[271]](#footnote-272)271

TENORM is also defined under general radiation provisions in a manner different than conventional definitions in other states such that TENORM is "N.O.R.M., which has been separated to various degrees from the original ore or other material, refining or implementing it." [[272]](#footnote-273)272

The lack of a consistent regulatory framework has led some to question whether TENORM waste is adequately addressed in Kentucky. Purported illegal dumping of fracking waste from West Virginia and Ohio has led to calls for legislative action to end loopholes that allow improper disposal to occur in Kentucky. [[273]](#footnote-274)273

13. Utah

Since commercial production began in 1948 in the Uinta Basin, Utah has produced more than 1.2 billion barrels of ***oil*** and more than 6 trillion cubic feet of natural gas. [[274]](#footnote-275)274 As of 2015, Utah has an estimated 27,352 wells. [[275]](#footnote-276)275 NORM, not TENORM, is subject to general licensing requirements, which set disposal limits of 15 pCi/g for Ra-226, with concentrations in excess of this limit requiring a radioactive material **[\*43]** license. [[276]](#footnote-277)276 While Utah does not specifically address TENORM or NORM generated in ***oil*** and gas operations, Utah does permit a LLRW facility to take in up to 10,000 pCi/g of Ra-226. [[277]](#footnote-278)277

14. New York

New York has an estimated 24,435 ***oil*** and gas wells. [[278]](#footnote-279)278 Under general radiation provisions, NORM is defined. TENORM containing waste is a regulated waste stream; however, TENORM is referred to as processed and concentrated NORM rather than TENORM. [[279]](#footnote-280)279

There is currently a state-wide fracking moratorium in New York, [[280]](#footnote-281)280 but environmentalists worry fracking waste is being imported from nearby Pennsylvania for disposal in New York. [[281]](#footnote-282)281 Thus, some are concerned that New York may not be properly addressing TENORM waste in the ***oil*** and gas industry from conventional drilling occurring in the state and wastes from unconventional drilling from outside the state. [[282]](#footnote-283)282

15. Montana

Montana has an estimated 19,928 wells. [[283]](#footnote-284)283 With the recent resurgence in the development of ***oil*** and gas resources in Montana [[284]](#footnote-285)284 and neighboring **[\*44]** states, the State developed new guidance. In 2013, Montana opened its first special oilfield waste facility. This facility can accommodate many of the wastes from neighboring North Dakota, which was only able to dispose of ***oil*** and gas wastes containing 5 pCi/g until 2015. [[285]](#footnote-286)285 Permit appeals or public hearings for such facilities are non-existent unlike in other states such as Colorado. [[286]](#footnote-287)286 Montana's Solid Waste Program (SWP) has developed landfill-management procedures to handle these drilling wastes. [[287]](#footnote-288)287 Under Montana rules, ***oil*** and gas wastes are commonly referred to as exploration and production (E&P) wastes. [[288]](#footnote-289)288

***Oil*** and gas wastes in Montana are considered exempt "nonhazardous E&P" wastes. [[289]](#footnote-290)289 These are regulated in Montana as a "'[s]pecial waste,' mean[ing] a solid waste that has unique handling, transportation, or disposal requirements to ensure protection of the public health, safety, and welfare and the environment." [[290]](#footnote-291)290 Minimum requirements for management of E&P wastes at licensed solid waste management facilities in Montana include:

(1) Analyzing unprocessed E&P waste for Radium-226, Radium-228, and Lead-210; and

(2) Analyzing processed E&P wastes for Radium-226, Radium-228, Lead-210, Thorium-232, and Polonium-210. [[291]](#footnote-292)291

Another significant requirement under the Montana guidance is creation and maintenance of a leachate collection and removal system with a synthetic liner that sets a limit of less than or equal to 50 pCi/g for Ra-226 and Ra-228. [[292]](#footnote-293)292 For all other leachate collection and removal system designs, the limit is less than or equal to 15 pCi/g for Ra-226 and Ra-228. [[293]](#footnote-294)293 **[\*45]** Finally, Montana established guidance for radioactive contamination of scale, sludge, and contaminated equipment. [[294]](#footnote-295)294

16. Michigan

Michigan has an estimated 19,821 wells. [[295]](#footnote-296)295 Michigan is not an agreement state. [[296]](#footnote-297)296 The State has, however, issued cleanup and disposal guidelines for sites contaminated with Ra-226. [[297]](#footnote-298)297 Unlike many other states, Michigan does not regulate disposal of Ra-228 because of the belief that it results in negligible amounts in waste streams. [[298]](#footnote-299)298 Instead, Michigan focuses on Ra-226. Michigan recommends the development of a regulatory framework for the handling of wastes containing Pb-210 as it can be further concentrated in natural gas streams. [[299]](#footnote-300)299

Michigan regulates disposal of up to 50 pCi/g of Ra-226 in Type I and Type II landfills (with no differentiation between landfills) and 5 pCi/g for soil cleanup criteria. [[300]](#footnote-301)300 Amounts more than 50 pCi/g should be transferred to a licensed radioactive waste facility. [[301]](#footnote-302)301 Michigan also requires disposal of TENORM at least 10 feet below the bottom of the landfill cap and leachate and groundwater monitoring for Ra-226. [[302]](#footnote-303)302 Michigan ***oil*** and gas **[\*46]** regulations govern plugged and abandoned wells. [[303]](#footnote-304)303 More than 50 pCi/g of waste must be transferred to a licensed radioactive waste facility. [[304]](#footnote-305)304

Michigan law defines naturally occurring material as "radioactive material found radioactive in the normal isotopic distribution of elements rather than rendered radioactive by artificial means." [[305]](#footnote-306)305 The Radioactive Materials Unit is responsible for NORM "found in ***oil***, gas, brine, chemical, and water treatment industries." [[306]](#footnote-307)306 The Supervisor of Wells and the Supervisor of Mineral Wells issued Order 3-6-92 that defines NORM and ways of disposing of it. [[307]](#footnote-308)307

17. Arkansas

Arkansas has 18,645 wells. [[308]](#footnote-309)308 The State's radiation control regulation provides NORM regulations; however, it is not specific to ***oil*** and gas. [[309]](#footnote-310)309 Facilities and equipment contaminated with NORM less than or equal to 50 μR/hr, including background, are exempt from licensure requirements. [[310]](#footnote-311)310 The exemption limit is "5 [pCi/g] of radium-226 and/or radium-228 . . . or 150 [pCi/g] of any other NORM radionuclide." [[311]](#footnote-312)311 Disposal methods at permitted facilities and licensed facilities adhere to general radiation provision guidelines as well as federal guidelines. [[312]](#footnote-313)312

18. North Dakota

North Dakota has 17,931 wells. [[313]](#footnote-314)313 North Dakota sits atop the Bakken Formation of the Williston Basin along with six other fields; experts estimate that the Bakken Formation contains at least 7 billion barrels of **[\*47]** recoverable ***oil*** reserves. [[314]](#footnote-315)314 The recent boom in shale gas extraction in North Dakota has prompted State officials to take several actions. [[315]](#footnote-316)315 The North Dakota Department of Health directed the North Dakota Argonne National Laboratory to conduct a study on TENORM to evaluate TENORM disposal in landfills and possible exposures to workers and the public. [[316]](#footnote-317)316 Following this study, licensure requirements for TENORM were enacted under the general radiation provisions, covering both worker protections and general public protections. [[317]](#footnote-318)317 Exemption limits for conventional disposal of TENORM, which includes both scale and sludge, is 5 pCi/g of Ra-226 and Ra-228 in any combination thereof. [[318]](#footnote-319)318 North Dakota also prohibits purposeful dilution to render TENORM exempt from the regulations. [[319]](#footnote-320)319

Changes were also made to solid-waste regulations, as it pertains to landfill disposal of TENORM waste. TENORM waste less than or equal to 50 pCi/g of Ra-226 and Ra-228 may be disposed of in a landfill, and a contaminated-equipment limit is set at 100 [mu]R/hr. [[320]](#footnote-321)320 Additionally, the "[d]isposal of TENORM waste subject to regulation under [general radiation provisions] is prohibited in all municipal solid waste landfills and inert landfills." [[321]](#footnote-322)321 The State requires monitoring of leachate and **[\*48]** groundwater analysis for background concentrations of radionuclide parameters before receipt of any TENORM waste. [[322]](#footnote-323)322 The regulations state:

If radionuclides are detected in the leachate at a concentration greater than the concentrations listed below, then the groundwater monitoring network must begin analysis for radionuclide parameters.

Radon: 4,000 picocuries per liter (pCi/L).

Combined radium-226 and radium-228: 5 pCi/L.

Alpha particle activity (including radium-226, excluding radon and uranium): 15 pCi/L.

Uranium: 30 micrograms per liter (ug/L) [sic]. [[323]](#footnote-324)323

Worker training and safety at landfills approved for the disposal of TENORM waste is implemented pursuant to regulations so that protection of workers complies with radiation protection standards. [[324]](#footnote-325)324

According to the North Dakota Department of Health's website, North Dakota has taken steps to specify that ***oil*** and gas disposal wells have leak proof, covered containers for disposal of radioactive filter socks. [[325]](#footnote-326)325 In addition, the transportation of TENORM waste now requires a radioactive transportation licensure. [[326]](#footnote-327)326 While North Dakota's measures are a step in the right direction, there are inconsistencies between the 5 pCi/g under general radiation provisions and the 50 pCi/g under waste management rules.

19. Tennessee

Tennessee has 15,814 wells, [[327]](#footnote-328)327 with drilling occurring in the Chattanooga Shale Formation. [[328]](#footnote-329)328 Tennessee has guidelines for TENORM disposal, which regulates the disposal of TENORM in accordance with the **[\*49]** following options for a licensee: "(a) [b]y transfer to an authorized recipient as provided in other chapters of these regulations; [or] (b) [b]y decay in storage;" or for the person receiving waste: "(a) [t]reatment prior to disposal; (b) [t]reatment or disposal by incineration; (c) [d]ecay in storage; or (d) [d]isposal at a licensed land disposal facility." [[329]](#footnote-330)329

20. Virginia

Virginia has 11,850 wells, [[330]](#footnote-331)330 and drilling occurs in the southwest part of the state in the organic-rich Marcellus Shale. State regulations generally address TENORM and NORM in its state radiation control regulations, but are not specific to ***oil*** and gas. [[331]](#footnote-332)331 As with most states that provide general radiation standards, the exemption limit for general disposal requirements is set at 5 pCi/g for Ra-226 and Ra-228, and 200 prem/hr at 1 cm for TENORM contaminated equipment. [[332]](#footnote-333)332

21. Mississippi

Mississippi has 7,897 wells. [[333]](#footnote-334)333 Since 1923, Mississippi has used natural gas to generate electricity, prompting the formation of the Mississippi ***Oil*** and Gas Board in 1932 as the regulatory body for the State's ***oil*** and gas industry. [[334]](#footnote-335)334 Mississippi has adopted rules governing the disposal of NORM in the ***oil*** and gas industry. [[335]](#footnote-336)335 NORM, not TENORM, is defined as "any nuclide which is radioactive in its natural physical state . . . but does not include byproduct, source or special nuclear material nor does it include radioactive materials continuously contained within the closed system of exploration and production of ***oil*** and gas, including but not limited to **[\*50]** produced saltwater. [[336]](#footnote-337)336 As outlined in the rule, the following are acceptable disposal methods:

(1) Placement between cement plugs; or

(2) Encapsulation in pipe then placed between cement plugs; or

(3) Mixed with gel or mud (slurried) and placed between cement plugs; or

(4) Slurried then placed into a formation; or

(5) Surface landspreading; or

(6) Subsurface landspreading; or

(7) Disposal offsite at a licensed, and low level radioactive waste or NORM disposal facility . . . . [[337]](#footnote-338)337

A land-spreading limit is set at 5 pCi/g, and the groundwater table must be located at least 5 feet from the bottom of the disposal area. [[338]](#footnote-339)338 All disposal options are outlined and must meet approved criteria set forth in the rule. Rule 69 of the regulations of the Mississippi ***Oil*** and Gas Board focuses on handling NORM in the field, which includes worker and public protections. [[339]](#footnote-340)339

Additionally, Mississippi regulates NORM through its general radiation provisions on licensing of NORM. [[340]](#footnote-341)340 The exemption limit concentration must be

less than 5 picocuries per gram of radium - 226 or radium - 228 above background; or, concentrations less than 30 picocuries per gram . . . of technologically enhanced radium-226 or radium-228, averaged over any 100 square meters, provided the radon emanation rate does not exceed 20 picocuries . . . per square meter per second, or 150 picocuries per gram . . . of any other NORM radionuclide . . . . [[341]](#footnote-342)341

Contaminated equipment should "not exceed 25 microroentgens per hour above background radiation at any accessible point. [[342]](#footnote-343)342

22. Nebraska

**[\*51]** Nebraska sits upon the Niobrara Shale Formation and has a total of 3,140 wells. [[343]](#footnote-344)343 Nebraska is not historically considered an area with a large natural gas play or an area with great reserves of ***oil***. However, because of advancements in hydraulic fracturing, the number of operating wells is increasing. [[344]](#footnote-345)344 A weak regulatory framework on disposal of TENORM wastes generated during operations may pose future problems and lead to radiological risks from exposure to wastes to workers and the public. [[345]](#footnote-346)345 TENORM is defined, and the exemption limit to radiation standards is set at 5 pCi/g for Ra-226 and its progeny, but may prove insufficient. [[346]](#footnote-347)346

23. Ohio

Ohio has 1,916 wells. [[347]](#footnote-348)347 Ohio sits atop the Utica Shale, which sits below the Marcellus Shale--a large reserve for natural gas that caused the production of shale gas to rise exponentially between 1990 and 2004. [[348]](#footnote-349)348 Ohio is one of the recent states to take measures to deal with fracking waste generated, including TENORM. [[349]](#footnote-350)349 Both NORM and TENORM are classically defined. [[350]](#footnote-351)350 The radiation control regulation on TENORM mentions worker and public protection in general without reference to ***oil*** and gas as part of a license requirement and release criteria. [[351]](#footnote-352)351 TENORM waste from ***oil*** and gas is under the jurisdiction of the ***Oil*** and Gas Division. [[352]](#footnote-353)352 The disposal limit at 5 pCi/g requires monitoring of leachate and groundwater for Ra-226, Ra-228, and others. [[353]](#footnote-354)353 Regulations define **[\*52]** scale and contaminated equipment in terms of TENORM. [[354]](#footnote-355)354 Per the Ohio Department of Health, TENORM must be tested before leaving the well for Ra-226 and Ra-228. [[355]](#footnote-356)355 Other ***oil*** and gas waste, such as brine containing NORM, is disposed of in underground injection wells and pursuant to a different set of standards and exempt from laws governing TENORM. [[356]](#footnote-357)356 This last part could prove to be problematic because of the distinction Ohio makes between NORM and TENORM, possibly opening the State to loopholes in the law.

Per radiation protection standards for TENORM, the exemption limit is set as 5 pCi/g of Ra-226 or Ra-228 and 50 [mu]R/hr for contaminated equipment. [[357]](#footnote-358)357 Thus, the solid waste landfill disposal limit of 5 pCi/g exists for Ra-226 and Ra-228, as authorized by the State. [[358]](#footnote-359)358 Scale is regulated as TENORM. Ohio requires that solid waste landfills and transfer facilities must first get TENORM analytical results for Ra-226 and Ra-228 before accepting waste from ***oil*** and gas drilling. [[359]](#footnote-360)359 24. Washington

Washington has 721 wells. [[360]](#footnote-361)360 While Washington does not have provisions regarding TENORM or NORM in their general radiation or ***oil*** and gas provisions, the State does permit a LLRW facility to accept up to 10,000 pCi/g of NORM. [[361]](#footnote-362)361 Like other states with little natural gas drilling activity, a minimum TENORM licensing requirement should be established with appropriate limits.

25. South Dakota

**[\*53]** South Dakota has 587 wells. [[362]](#footnote-363)362 The first producing ***oil*** well was drilled in 1953, and drilling mostly takes part in the northeast part of the state in the Bakken Shale Formation in the Williston Basin. [[363]](#footnote-364)363 Given the small number of wells in the state, new legislative measures may not be necessary for TENORM-bearing wastes in the ***oil*** and gas industry. South Dakota is not, however, an agreement state nor does it generally license TENORM. [[364]](#footnote-365)364 Interestingly, South Dakota has provisions prohibiting the disposal of more than 5 pCi/g Ra-226 and Ra-228 in solid waste disposal facilities in the state. [[365]](#footnote-366)365

26. Oregon

Oregon has 522 wells. [[366]](#footnote-367)366 NORM, not TENORM, is licensed under general radiation provisions, which set the limit for conventional disposal options at 5 pCi/g for radium and 150 pCi/g of any NORM nuclide. [[367]](#footnote-368)367 Contaminated equipment is addressed in the context of NORM; however, scale, sludge, produced water, and drill cuttings are not. [[368]](#footnote-369)368 These regulations are not specific to ***oil*** and gas, and they do not address TENORM.

27. Arizona

Arizona has 369 wells. [[369]](#footnote-370)369 Despite the low number of wells and activity, the ***Oil*** and Gas Commission established a set of guidelines pertaining to these operations. [[370]](#footnote-371)370 Neither Arizona's regulations nor general radiation provisions, however, include TENORM or NORM waste. [[371]](#footnote-372)371 Thus, Arizona may inadequately dispose of TENORM waste.

28. Idaho

**[\*54]** Idaho has 152 wells. [[372]](#footnote-373)372 TENORM and NORM are covered under general radiation provisions. [[373]](#footnote-374)373 Outside of the general radiation provisions, TENORM is covered under the solid waste management regulations, which prohibit the disposal of TENORM at solid waste disposal facilities; thus, disposal can only occur at RCRA Subtitle C landfills. [[374]](#footnote-375)374 These TENORM regulations set exposure limits for members of the public, but lack specificity as to measuring exposure. [[375]](#footnote-376)375 While Idaho may not be a major producer of ***oil*** and gas, other states may not dispose of TENORM waste in State municipal solid waste landfills, but only at RCRA Subtitle C landfills. [[376]](#footnote-377)376 A RCRA Subtitle C facility run by U.S. Ecology does, in fact, accept up to 1,500 pCi/g of TENORM wastes containing radium, and receives ***oil*** and gas wastes from as far as Pennsylvania. [[377]](#footnote-378)377

*B. States with Active Wells that Have No NORM & TENORM Regulations*

The next grouping of states does not address NORM or TENORM in any of their state laws or regulations.

Alabama has 8,017 wells. [[378]](#footnote-379)378 Alabama's first ***oil*** wells were drilled in 1865 and commercially drilled since the 1900s. [[379]](#footnote-380)379 In the late 1970s, reserves were discovered offshore in the Gulf of Mexico, and a few years later coalbed natural gas reserves were drilled in the Black Warrior River. [[380]](#footnote-381)380 The rise in production prompted the Alabama ***Oil*** and Gas Board to establish the State's first set of comprehensive drilling operations laws. These laws do not, however, account for today's technological advances in shale gas extraction. Controversy has loomed over Alabama's shale gas extraction industry. [[381]](#footnote-382)381 For example, protests ended attempts to lease over 40,000 acres in the Talladega National Forest. [[382]](#footnote-383)382 Alabama's laws and **[\*55]** regulations do not adequately define waste from TENORM and NORM, despite the State's long history of ***oil*** and gas production. [[383]](#footnote-384)383

Indiana has 7,672 wells, [[384]](#footnote-385)384 Missouri has 6,590 wells, [[385]](#footnote-386)385 and Alaska has 5,643 wells. [[386]](#footnote-387)386 These states are not agreement states and do not have regulations addressing TENORM or NORM disposal. [[387]](#footnote-388)387

Florida has 123 wells. [[388]](#footnote-389)388 Florida is an agreement state, but Florida does not define TENORM or NORM in any of its laws or codes. The limited number of wells and reserves in the state do not necessitate massive changes in current regulatory standards. The State's general radiation provisions should at least define TENORM and NORM, which would provide necessary worker and public health protections.

Maryland is also an agreement state [[389]](#footnote-390)389 and has only 57 wells. [[390]](#footnote-391)390 Until October 1, 2017, the State did not permit hydraulic fracturing. [[391]](#footnote-392)391

*C. NORM & TENORM Regulations in States Without* ***Oil*** *& Gas Drilling*

The following states have no drilling operations. [[392]](#footnote-393)392 South Carolina covers licensing of NORM and TENORM establishing conventional requirements for worker and public protections. [[393]](#footnote-394)393 South Carolina's NORM regulations provide an exemption limit for contaminated equipment of 50 [mu]R/hr. [[394]](#footnote-395)394 The exemption limits for NORM radionuclides include: (1) 30 pCi/g or less of technologically enhanced Ra-226 or Ra-228 if the radon emanation rate is less than 20 pCi per square meter per second; (2) 5 pCi/g or less of technologically enhanced Ra-226 or Ra-228 if the radon emanation rate is greater than or equal to 20 pCi per square meter per **[\*56]** second; and (3) 150 pCi/g or less of any other NORM radionuclide. [[395]](#footnote-396)395 These protections would be sufficient at a minimum.

New Jersey does not have any active drilling wells. [[396]](#footnote-397)396 Still, the State may be improperly addressing disposal of TENORM waste imported into the state. For instance, New Jersey disposes of drill cuttings and drilling waste from neighboring states such as Pennsylvania. [[397]](#footnote-398)397 New Jersey's general radiation provisions define NORM and TENORM and can serve as a standard for disposal amounts. [[398]](#footnote-399)398 Currently, New Jersey limits TENORM licensing to 5 pCi/g for Ra-226 or Ra-228. [[399]](#footnote-400)399 Additionally, New Jersey provides guidelines for minimum remediation standards for TENORM contaminated sites. These guidelines may benefit New Jersey, considering the State accepts imported TENORM waste. [[400]](#footnote-401)400 Another Mid-Atlantic state, Delaware, is not an agreement state [[401]](#footnote-402)401 and does not define TENORM. [[402]](#footnote-403)402

Georgia's NORM licensing requirements define NORM and TENORM. [[403]](#footnote-404)403 Like South Carolina, Georgia distinguishes between NORM and TENORM in setting conventional disposal limits. For example, Georgia exempts:

(1) 30 picocuries . . . per gram or less of technologically-enhanced radium-226 or radium-228 . . . [if] the radon emanation rate is less than 20 pCi . . . per square meter per second or;

(2) 5 pCi . . . per gram or less of technologically-enhanced radium-226 or radium-228 . . . [if] the radon emanation rate is equal to or greater than 20 pCi . . . per square meter per second; or

(3) 150 pCi . . . or less per gram of any other NORM radionuclide . . . . [[404]](#footnote-405)404

Georgia's regulations also address contaminated equipment and scale, limiting contaminated equipment to 50 [mu]R/hr. [[405]](#footnote-406)405

**[\*57]** New England lacks abundant, if any, ***oil*** and gas reserves. Thus, these states do not typically address NORM or TENORM waste. Vermont is not an agreement state. [[406]](#footnote-407)406 Vermont law prohibits hydraulic fracturing for ***oil*** and gas. Additionally, Vermont prohibits handling wastewater from hydraulic fracturing operations. [[407]](#footnote-408)407 Massachusetts defines NORM, but not TENORM. [[408]](#footnote-409)408 Connecticut, which is not an agreement state, [[409]](#footnote-410)409 prohibits the transfer and disposal of hydraulic fracturing waste. [[410]](#footnote-411)410 New Hampshire's general radiation standards define NORM. [[411]](#footnote-412)411 Rhode Island regulations and laws do not address TENORM or NORM. Lastly, Maine regulations define TENORM and provide for classic disposal options limited to 5 pCi/g of any combination of Ra-226 or Ra-228. [[412]](#footnote-413)412 Maine's general radiation provisions protect workers and the public; however, these protections are not specific to ***oil*** and gas. [[413]](#footnote-414)413 Maine's TENORM licensing provisions address contaminated equipment, but fail to address sludge, scale, produced water, or drill cuttings. [[414]](#footnote-415)414

Additionally, Minnesota, Iowa, Wisconsin, Hawaii, and the District of Columbia have no ***oil*** and gas activity and no specific NORM or TENORM guidelines. [[415]](#footnote-416)415 Similarly, North Carolina is not producing natural gas or ***oil*** [[416]](#footnote-417)416 and lacks TENORM or NORM regulations. In 2014, however, the North Carolina State Legislature passed the Energy Modernization Act. [[417]](#footnote-418)417 This Act lifted the ban on ***oil*** and gas exploration, allowing possible extraction of the State's shale gas. [[418]](#footnote-419)418 Like North Carolina, Nevada has engaged in limited or no shale ***oil*** and gas extraction. [[419]](#footnote-420)419 However, the **[\*58]** Eastern Great Basin's potential for ***oil*** and gas extraction may influence Nevada's participation in the industry. [[420]](#footnote-421)420

VI. BY THE NUMBERS

Table 3 describes how many states allow different disposal options for TENORM and NORM in the ***oil*** and gas industry.

| **Disposal Options for** | **# of States** | **States** |
| --- | --- | --- |
| **TENORM/NORM** |  |  |
|  |  | Arkansas, Georgia, Idaho, |
|  |  | Kentucky, Louisiana, |
|  |  | Maine, Mississippi, |
| Disposal at a Licensed Land | 18 | Montana, New Mexico, |
| Disposal Facility |  | New York, North Dakota, |
|  |  | Ohio, Oregon, South |
|  |  | Carolina, Tennessee, Texas, |
|  |  | Virginia, West Virginia |
| Disposal at a Low-Level | 4 | Mississippi, Washington, |
| Radioactive Waste Facility |  | Utah, Illinois |
|  |  | California, Colorado, Idaho, |
|  |  | Louisiana, Maine, |
| Disposal at a Permitted Solid | 12 | Michigan, Montana, New |
| Waste Disposal Facility |  | Mexico, North Dakota, |
|  |  | Ohio, South Dakota, |
|  |  | Wyoming |
| Disposal in Plugged and | 3 | New Mexico, Texas, |
| Abandoned Wells |  | Mississippi |
| Burial | 3 | Texas, Colorado, North |
|  |  | Dakota |
| Land-spreading | 4 | New Mexico, Texas, |
|  |  | Kansas, Mississippi |
| Incineration | 3 | Kentucky, South Carolina, |
|  |  | Tennessee |
|  |  | Colorado, Maine, |
| Deep Well Injection | 7 | Michigan, Mississippi, New |
|  |  | Mexico, Ohio, Texas |
| Disposal in Non-Retrieved | 1 | New Mexico |
| Flowlines and Pipelines |  |  |
| Reuse | 1 | Colorado |
|  |  | Colorado, Kentucky, |
| Treatment Prior to Disposal | 5 | Louisiana, South Carolina, |
|  |  | Tennessee |

**[\*59]** Table 4 describes the permissible disposal limits and disposal options for TENORM and NORM by state.

| **States with Limits** | **Limits (pCi/g)** | **Type of** |
| --- | --- | --- |
|  |  | **Permit/Disposal** |
| Texas | 30 pCi/g for Ra-226 | State rule for |
|  | and Ra- 228 | general disposal, |
|  |  | land-spreading, |
|  |  | disposal by burial |
| Kansas | 10 pCi/g for Ra-226 | Land-spreading |
|  | and Ra- 228 |  |
| California | 1,800 TENORM waste | Disposal permit at |
|  |  | permitted facility |
| Colorado | 2,000 TENORM waste | Disposal permit at |
|  |  | permitted facility |
| Illinois | 2,000 TENORM waste | Disposal permit at |
|  |  | LLRW facility |
| Wyoming | 30 pCi/g up to 20 | Disposal at a |
|  | cubic yards; 30-50 | permitted solid |
|  | pCi/g up to 10 cubic | waste disposal |
|  | yards; 50 piC/g | facility |
| Louisiana | 30 pCi/g Ra-226 and | Disposal at a |
|  | Ra-228 for | licensed land |
|  | nonhazardous | disposal facility, |
|  | oilfield waste at | disposal at a |
|  | commercial | permitted solid |
|  | facilities; 200 | waste disposal |
|  | pCi/g Ra-226 and/or | facility, treatment |
|  | Ra-228 at a licensed | prior to disposal |
|  | treatment facility |  |
| New Mexico | 30 pCi/g for Ra-226 | Disposal at a |
|  | and 150 pCi/g for | permitted solid |
|  | any NORM | waste disposal |
|  | radionuclide | facility, disposal |
|  |  | in plugged and |
|  |  | abandoned wells, |
|  |  | land-spreading, deep |
|  |  | well injection, |
|  |  | disposal in |
|  |  | non-retrieved |
|  |  | flow-lines and |
|  |  | pipelines |
| Kentucky | 2,000 pCi/g TENORM | Disposal permit at |
|  | waste | LLRW facility |
| Montana | 50 pCi/g for | Disposal at a |
|  | Leachate Collection | permitted solid |
|  | and Removal System | waste disposal |
|  | and Synthetic Liner | facility |
|  | and 15 pCi/g for |  |
|  | natural clay liner |  |
|  | for combined Ra-226 |  |
|  | and Ra-228 |  |
| Michigan | 50 pCi/g for Ra-226 | Disposal at a |
|  |  | permitted solid |
|  |  | waste disposal |
|  |  | facility |
| North Dakota | 50 pCi/g for Ra-226 | Disposal at a |
|  | and/or Ra-228 | permitted solid |
|  |  | waste disposal |
|  |  | facility, burial |
| Mississippi | 5 pCi/g for Ra-226 | Land-spreading |
|  | and Ra-228 |  |
| Ohio | 5 pCi/g for Ra-226 | Disposal at a |
|  | and Ra- 228 | licensed land |
|  |  | disposal facility, |
|  |  | disposal at a |
|  |  | permitted solid |
|  |  | waste disposal |
|  |  | facility, deep well |
|  |  | injection, treatment |
|  |  | prior to disposal |
| Washington | 10,000 pCi/g TENORM | Disposal at a LLRW |
|  | waste | facility |
| South | N/A | Disposal at a permitted solid waste |
| Dakota |  | disposal facility |

CONCLUSION

Texas, Pennsylvania, Oklahoma, Louisiana, and Wyoming are the top five greatest producers of ***oil*** and gas. Many states may be inadequately addressing drilling wastes generated by ***oil*** and gas extraction. Complicating the issue, regulating agencies may confront jurisdictional overlap while regulating NORM and TENORM waste. Clear guidance, laws, and regulations are necessary to facilitate safety and health in states where inadequacies could harm humans, animals, and the environment.

The problem presents two questions. First, how do ***oil*** and gas producing states dispose of the resulting waste? Second, how do states receiving waste from others ensure adequate protection? States with long histories of ***oil*** and gas exploration, such as Texas and New Mexico, have established disposal options that may minimize the amount of waste exported. But, with new technologies [[421]](#footnote-422)421 such as high-volume hydraulic fracturing [[422]](#footnote-423)422 and horizontal drilling, [[423]](#footnote-424)423 some states are experiencing a boom in natural gas production, [[424]](#footnote-425)424 creating more waste. Although Connecticut has no active wells, the State has forbidden the importation of any ***oil*** and gas waste. Additionally, Pennsylvania transports most of its drilling waste to New York, Ohio, New Jersey, Maryland, and West Virginia; these states may not have adequate protections for workers and the public, especially **[\*62]** considering the alarming amount of waste disposed of in "unspecified locations." [[425]](#footnote-426)425

States such as Pennsylvania and North Dakota are experiencing a boom in their economies from ***oil*** and gas extraction in the Marcellus and Bakken shales. [[426]](#footnote-427)426 States with bans on fracking, or those with limited ***oil*** and gas resources, also receive indirect economic benefit by importing these wastes. [[427]](#footnote-428)427 New York, for instance, does not permit shale gas extraction. Since New York accepts waste imports from Pennsylvania, it should consider expanding regulatory protections, and perhaps limit the amount of waste it imports. [[428]](#footnote-429)428

States should outline specific criteria and detailed requirements of disposal options as well as tracking manifests. New Mexico has adopted comprehensive waste disposal laws and could serve as a model for other states. Specifically, New Mexico requires a survey of TENORM waste prior to leaving the well site. [[429]](#footnote-430)429 Other states, like Michigan and Pennsylvania, designate TENORM waste to areas in landfills equipped to handle radioactivity. [[430]](#footnote-431)430 These processes, coupled with continuous monitoring, may present one requirement for states to consider.

Texas and Louisiana have adopted regulatory limits that are perhaps less protective than the 5 pCi/g limit. These limits may, however, be more representative of the waste generated during ***oil*** and gas operations. Depending on the disposal option, tiered TENORM disposal limits may be prudent. States should reevaluate these options to determine the best disposal methods based on geology, topography, risks, etc.

Some states, such as Wyoming and Pennsylvania, have chosen not to regulate low-risk TENORM waste. Yet, studies cited in this article suggest that low-dose exposure to TENORM may be harmful to human health and the environment due to the radiological risks. States should set exposure limits based on engineering, medical, and public-health perspectives. Thus, future studies should look at these regulatory limits as they relate to human and environmental health.

Texas takes measures to prohibit disposal options that may unnecessarily cause overexposure to radioactive waste. Other states, which allow for widespread unconventional ***oil*** and gas operations, should also **[\*63]** develop policies, guidance, or regulations addressing ambiguities in their general radiation provisions.

Many states rely on their general radiation provisions to cover NORM and TENORM wastes, but this could prove problematic given the dichotomy of ***oil*** and gas operations. States with abundant production totals must enact measures addressing drilling wastes. Oklahoma has no general radiation provisions, and therefore does not regulate TENORM waste generated during ***oil*** and gas production.

This lack of protection for these workers and nearby residents potentially exposes them to unnecessary radiation risks. States should incorporate worker and public safety measures that consider unconventional ***oil*** and gas operations. States should adopt guidance for site safety and health plans for ***oil*** and gas operations. As one example, workers should wear badges that monitor exposures during upstream and downstream activities. Additionally, states should implement engineering and institutional controls including cleaning contaminated equipment in well-ventilated areas or limiting worker exposures through shift changes.

Unconventional ***oil*** and gas production is controversial. Proponents argue that natural gas is relatively cleaner and more economically sustainable for producers, manufacturers, businesses, and individuals. Opponents cite to pollution and radiological concerns that can negatively impact human and environmental health. On a broader level, some state policies hinder the options available for TENORM disposal. Thus, prudence requires safe and effective ways for reducing TENORM waste.

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