RADIATION RISKS AND FRACKING WASTE STREAMS

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1. INTRODUCTION

This submission will only address one area of concern as it relates to the Terms of Reference outlined in the NT Government's Hydraulic Fracturing Inquiry; that of radioactive waste management as it pertains to oil and gas fracking. The author has an Hons. 1 degree in Public Health, a PhD in Science and Technology Studies for a thesis examining the merits of whether to replace Australia's nuclear research reactor, and 20 years experience as a researcher and campaigner on the environmental and public health impacts of the nuclear industry including those relating to radiation releases and exposure.

Many of the studies referenced here have been undertaken in the United States shale gas provinces and the United Kingdom. With no currently operating shale gasfields in Australia to draw conclusions from it is important we look beyond our limited domestic experience to understand the risks posed by the production of radioactive waste streams via the fracking process.

Oil and gas fracking generates several radioactive waste streams including mineral scales inside pipes; sludges/sediments; contaminated equipment or components; and produced waters. Because the extraction process concentrates naturally occurring radionuclides and exposes them to the surface environment, these wastes are classified as Technologically Enhanced Naturally Occurring Radioactive Material (TENORM).

In some circumstances, these radioactive materials (esp. sludges/sediment) can meet the criteria for classification as Low Level Radioactive Waste. In the Northern Territory, the government must resolve the issue of how to store or dispose of materials that meet the criteria for classification as Low Level Radioactive Waste given that there is no repository for such waste in the NT (nor is there a national repository).

Radiation levels can vary dramatically depending on the geological radioactivity and processing methods (e.g. recycling of fracking waste water can generate a sludge meeting the criteria for classification as Low Level Radioactive Waste).

The approach by industry and government regulatory agencies to the management of radioactive fracking wastes has been uneven and generally poor, as discussed in subsequent sections. Illegal dumping is clearly a problem, and necessitates a thorough monitoring regime as well as enforcement and penalties. A proactive approach is required, whereas responses in the US, the UK and elsewhere have generally been reactive.

It is recommended that further fracking activity in the Northern Territory should not proceed on the basis there is an inadequate industry management and regulatory system in place to avoid harm from the radioactive waste streams generated by the industry. Such an approach will fail to avoid the costly, complex, and long-term management issues posed by these waste streams that have significantly impacted other fracking provinces. The industry has yet to demonstrate the production of these streams of radioactive waste can be adequately managed to avoid harm and costs to the broader economy and local environment.

It is recommended that the inquiry should look into the follow proactive management approach and whether it could be implemented in such a way to reduce negative impacts:

- Implement NT legislation governing the best practice management of radioactive wastes from fracking.
- Clearly specified management / disposal routes for radioactive wastes along with a communications program such that companies are aware of their obligations.
- Increased resourcing for regulatory agencies to establish systematic monitoring of fracking companies and their management of radioactive waste streams.
- Strong penalties for companies failing to meet their obligations.
- A permit and training system such that companies planning to generate radioactive wastes as a byproduct of fracking must demonstrate that
    - i) they have the requisite technical knowledge regarding waste streams and appropriate precautions,
    - ii) ii) they clearly understand government requirements regarding the management of different radioactive waste streams, and
    - iii) iii) companies understand the penalties for non-compliance.

2. NT RADIOACTIVE WASTE MANAGEMENT PRACTICES ON CURRENT FRACK SITES

An Environmental Management Plan produced for Origin Energy's Amungee Mungee frack site near Daly Waters in the Northern Territory demonstrates the paucity of the current regulatory framework to manage new streams of radioactive wastes being produced through fracking operations.

The report, produced by fracking company Origin Energy, identifies in its risk matrix a medium-level risk that well stimulation could harm workers and the environment through the production of Radioactive elements (NORMs) and its inadequate disposal.[1]

It identifies potential damage to the ecosystem or radioactive exposure to personnel in the handling or inadequate disposal of radioactive drill cuttings, sludge, scales and other waste streams.

The matrix states that Origin will take precautions to address or minimise this risk by undertaking 'adequate' disposal of NORMs, limiting exposure time for personnel and that NORMs testing will be undertaken throughout the programme. No definition for 'adequate' disposal has been provided by Origin.

The risk matrix further identifies as a mitigation measure for the management of drill cuttings, including radioactive material, that: "Drill cuttings that are acidic, radioactive or of a substantially different colour to the surface soil should be backfilled in the drill hole, sump or other excavation. All other cuttings should be dispersed around the site or raked over."

Given that this particular frack site is within the boundaries of a working cattle station and in a region prone to heavy flooding it is concerning that radioactive materials that are buried or raked into the surface subsoil could enter the food chain or be dispersed across the landscape.

It is recommended that the Inquiry investigate the potential risk that possibly thousands of new shallow radioactive waste pits will be produced across Northern Territory landscapes for the shale gas industry, including farming and pastoral lands.

Many other proposed frack sites within the Northern Territory are located within proximity to lands and waterways purposed for food growing and cattle production, and subsoil contamination poses a serious concern to many landholders. The Inquiry should determine whether the current practices concerning on-site disposal meet best practice requirements for the safe management of radioactive materials.

Further it is recommended that the management of radioactive materials and the cumulative environmental and economic risks be assessed as part of ongoing studies.

Due to the high likelihood of disposal of contaminants back into the local environment, a chain of responsibility must be identified and made public for the disposal of radioactive waste product produced on frack sites.

Personnel must be required to be trained in the safe handling and disposal of wastes. Operators should be required to hold a radioactive waste handling permit and install radiation monitors at all frack sites and landfills that accept drilling wastes.

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[1] Appendix E, Risk Assessment, https://minerals.nt.gov.au/__data/assets/pdf_file/0008/377162/Stimulation-and-well-test-environmental-plan-reducted.pdf

It is recommended that this Inquiry undertake a review of current regulations and waste management capabilities and practices in the Northern Territory to determine the risks of substantially increasing production volumes of fracking-associated radioactive waste streams across remote locations, particularly as it relates to human and environmental health.

The Inquiry must determine the volumes of waste produced at frack sites that could be classified as conventional waste, and buried on site or sent to landfill, or that might meet the radiological criteria requiring management as Low Level Radioactive Waste, and the options (if any) for its disposal.

3. RADIOACTIVE CONTAMINANTS AND WASTE ARISING FROM FRACKING

The US EPA provides a general introduction to the issue of fracking waste, in particular radioactive materials:[2]

In recent years, oil and gas producers have employed new methods that combine horizontal drilling with enhanced stimulation. These new methods, known as "fracking", have changed the profile of oil and gas wastes – both in terms of radioactivity and volumes produced. The geologic formations that contain oil and gas deposits also contain naturally-occurring radionuclides, which are referred to as Naturally Occurring Radioactive Materials (NORM):

- *Uranium and its decay products.*
- *Thorium and decay products.*
- *Radium and decay products.*
- *Potassium-40.*
- *Lead-210/Polonium-210.*

Much of the petroleum and natural gas developed in the U.S. was created in the earth's crust at the site of ancient seas by the decay of sea life. As a result, these shale, petroleum and gas deposits often occur in aquifers containing brine (salt water). Radionuclides, along with other minerals that are dissolved in the brine, separate and settle out, forming various wastes at the surface:

- *Mineral scales inside pipes.*
- *Sludges/sediments.*
- *Contaminated equipment or components.*
- *Produced waters.*

Because the extraction process concentrates the naturally occurring radionuclides and exposes them to the surface environment and human contact, these wastes are classified as Technologically Enhanced Naturally Occurring Radioactive Material (TENORM).[3]

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[2] US EPA, 'TENORM: Oil and Gas Production Wastes', www.epa.gov/radiation/tenorm-oil-and-gas-production-wastes

[3] www.epa.gov/radiation/technologically-enhanced-naturally-occurring-radioactive-materials-tenorm

How are drilling wastes produced?

The briney solution contained in reservoirs of oil and gas is known as "formation water." During drilling, a mixture of oil, gas, and formation water is pumped to the surface. The water is separated from the oil and gas into tanks or pits, where it is referred to as "produced water." As the oil and gas in the formation are removed, much of what is pumped to the surface is formation water. Consequently, declining oil and gas fields generate more produced water.

While uranium and thorium are not soluble in water, their radioactive decay products such as radium may dissolve in the brine. They may remain in solution or settle out to form sludges that accumulate in tanks and pits, or form mineral scales inside pipes and drilling equipment.

How much radioactivity is in the wastes?

Radium levels in the soil and rocks vary greatly, as do their concentrations in scales and sludges. Radiation levels may vary from background soil levels to as high as several hundred picocuries per gram (pCi/g). The variation depends on several factors:

- *Concentration and identity of the radionuclides.*
- *Chemistry of the geologic formation.*
- *Characteristics of the production process.*

Produced Waters

Produced waters are waters pumped from wells and separated from the oil and gas produced. The radioactivity levels in produced waters from unconventional drilling can be significant and the volumes are large. ...

Scale

Scale is composed primarily of insoluble barium, calcium, and strontium compounds that precipitate from the produced water due to changes in temperature and pressure. Radium is chemically similar to these elements and as a result is incorporated into the scales. Concentrations of Radium-226 are generally higher than those of Ra-228.

Scales are normally found on the inside of piping and tubing. API found that the highest concentrations of radioactivity are in the scale in wellhead piping and in production piping near the wellhead. Concentrations were as high as tens of thousands of picocuries per gram. However, the largest volumes of scale occur in three areas:

- *Water lines associated with separators, (separate gas from the oil and water).*
- *Heater treaters (divide the oil and water phases).*
- *Gas dehydrators, where scale deposits as thick as four inches may accumulate.*

Chemical scale inhibitors may be applied to the piping complexes to prevent scales from slowing the oil extraction process. If the scales contain TENORM, the radiation will remain in solution and eventually be passed on to the produced waters.

Approximately 100 tons of scale per oil well are generated annually in the United States. As the oil in a reservoir dwindles and more water is pumped out with the oil, the amount of scale increases. In some cases brine is introduced into the formation to enhance recovery; this also increases scale formation.

The average radium concentration in scale has been estimated to be 480 picocuries per gram (pCi/g). It can be much higher (as high as 400,000 pCi/g) or lower depending on regional geology. Scale in gas wells and equipment can also contain the radon progeny lead-210 (Pb-210) and polonium-210 (Po-210) (see below).

<u>Sludge</u>

Sludge is composed of dissolved solids which precipitate from produced water as its temperature and pressure change. Sludge generally consists of oily, loose material often containing silica compounds, but may also contain large amounts of barium. Dried sludge, with a low oil content, looks and feels similar to soil.

Oil production processes used in conventional drilling generate an estimated 230,000 MT or five million cubic feet (141 cubic meters) of TENORM sludge each year. API has determined that most sludge settles out of the production stream and remains in the oil stock and water storage tanks.

Like contaminated scale, sludge contains more Ra-226 than Ra-228. The average concentration of radium in sludges is estimated to be 75 pCi/g. This may vary considerably from site to site. Although the concentration of radiation is lower in sludges than in scales, sludges are more soluble and therefore more readily released to the environment. As a result they pose a higher risk of exposure.

The concentration of lead-210 (Pb-210) is usually relatively low in hard scales but may be more than 27,000 pCi/g in lead deposits and sludge.

<u>Contaminated Equipment</u>

TENORM contamination levels in equipment varied widely among types of equipment and geographic region. ... According to an API industry-wide survey from the 1990s, approximately 64 percent of the gas producing equipment and 57 percent of the oil production equipment showed radioactivity at or near background levels for conventional sites. TENORM radioactivity levels tend to be highest in water handling equipment. Average exposure levels for this equipment were between 30–40 microroentgens per hour (µR/hr), which is about five times background.

The Guardian in 2013 reported[4] on a university study[5] which found dangerous levels of radioactivity at fracking waste site in the US:

"Scientists have for the first time found dangerous levels of radioactivity and salinity at a shale gas waste disposal site that could contaminate drinking water. … The Duke University study … examined the water discharged from Josephine Brine Treatment Facility into Blacklick Creek, which feeds into a water source for western Pennsylvania cities, including Pittsburgh. Scientists took samples upstream and downstream from the treatment facility over a two-year period, with the last sample taken in June this year.

"Elevated levels of chloride and bromide, combined with strontium, radium, oxygen, and hydrogen isotopic compositions, are present in the Marcellus shale wastewaters, the study found.

"Radioactive brine is naturally occurring in shale rock and contaminates wastewater during hydraulic fracturing – known as fracking. Sometimes that "flowback" water is re-injected into rock deep underground, a practice that can cause seismic disturbances, but often it is treated before being discharged into watercourses.

"Radium levels in samples collected at the facility were 200 times greater than samples taken upstream. Such elevated levels of radioactivity are above regulated levels and would normally be seen at licensed radioactive disposal facilities, according to the scientists at Duke University's Nicholas school of the environment in North Carolina.

"Hundreds of disposal sites for wastewater could be similarly affected, said Professor Avner Vengosh, one of the authors of the study published in Environmental Science & Technology, a peer-reviewed journal. "If people don't live in those places, it's not an immediate threat in terms of radioactivity," said Vengosh. "However, there's the danger of slow bio-accumulation of the radium. It will eventually end up in fish and that is a biological danger."

"Shale gas production is exempt from the Clean Water Act and the industry has pledged to self-monitor its waste production to avoid regulatory oversight. However, the study clearly showed the need for independent monitoring and regulation, said Vengosh. "What is happening is the direct result of a lack of any regulation. If the Clean Water Act was applied in 2005 when the shale gas boom started this would have been prevented." …

"The US Geological Service has previously reported elevated levels of radioactivity in "flowback" water that naturally occurs in the rock. But the Duke study, called Impacts of Shale Gas Wastewater Disposal on Water Quality in Western Pennsylvania, is the first to use isotope hydrology to connect the dots between shale gas waste, treatment sites and discharge into drinking water supplies."

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[4] The Guardian, 2 Oct 2013, 'Dangerous levels of radioactivity found at fracking waste site in Pennsylvania', www.theguardian.com/environment/2013/oct/02/dangerous-radioactivity-fracking-waste-pennsylvania

[5] 'Impacts of Shale Gas Wastewater Disposal on Water Quality in Western Pennsylvania', http://pubs.acs.org/doi/abs/10.1021/es402165b

Alan Herbert, director of a hydrogeological consultancy company, and Trevor Jones, director of a waste management consultancy and also the UK Business Development Manager for NucTecSolutions GmbH, discuss problems dealing with radioactive materials released by fracking:[6]

"If fracking is to be a viable option for energy production, the industry must find a way to deal with the naturally occurring radioactive materials (NORM) that are released as a byproduct of the process. ...

"The process of fracking involves pumping water and chemicals deep under ground to break apart the shale rocks and release the gas they contain. Much of this water returns to the surface as flowback, bringing with it pore fluid released from the shale. The initial flowback mainly consists of the clean water that was injected, but once most of this has returned to the surface the fluid will contain a higher proportion of pore water. This means increasing levels of radioactive radium and dissolved radon gas.

"Radon will be present in the gas stream, just as with conventional gas resources, but generally at very low concentrations. It is minimal enough to fall under the radar of radioactive substances regulation. But the concentration of naturally occurring radioactive material that is found in the waste water, principally radium, is high enough to be of regulatory concern.

"Concentrations of NORM in the flowback must be monitored, along with the deposits of scale and sludge that get left on the inside of pipes and other equipment.

"These issues are similar to those that arise during conventional oil and gas production, which also generate large volumes of water as a by-product of extraction. But the amount of NORM in water found in conventional oil and gas reservoirs tends to be lower than in shale gas flowback. ...

"Fracking produces very large volumes of waste water and, due to the concentration of NORM it contains, a permit is required to manage it. As yet, there is no economic way to clean up the waste water for drinking or irrigation purposes, but other dissolved minerals and rock debris can be removed to allow its reuse to frack additional wells.

"Reusing flowback like this minimises the volume of water used in fracking − but does not avoid the problem of having large volumes of radioactively contaminated waste water that needs to be managed. Some estimates[7] suggest widespread exploitation of the UK's shale gas reserves would increase the national waste water treatment requirement by as much as 3%. And conventional waste water treatment methods are generally not able to remove the radioactive materials effectively.

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[6] Alan Herbert & Trevor Jones, 5 March 2014, 'Fracking's radioactive legacy − we lack the technology', www.theecologist.org/blogs_and_comments/commentators/2308416/frackings_radioactive_legacy_we_lack_the_technology.html

[7] www.gov.uk/government/uploads/system/uploads/attachment_data/file/273997/DECC_SEA_Environmental_Report.pdf

"The industry needs a plan – and right now, it hasn't got one. Though the technology to remove radioactive contaminants from waste water exists, it is both expensive and difficult, depending on the concentrations of other contaminants that are present. It's also not readily available for treatment of the volumes of waste water likely to be produced as a result of the full commercial exploitation of UK shale gas.

"The management and disposal of the scales and sludges left on exploration and production equipment will also be an issue for the shale gas industry – though treatment technologies and disposal routes for this are more readily available. The UK's nascent shale gas industry must have a plan in place to deal with the byproducts of fracking. It will require careful management to ensure that any radiological material does not become a health or environmental hazard."

A 2013 report by the U.S. Union of Concerned Scientists discusses the problems of water consumption as well as contamination with fracking chemicals:[8]

"Natural gas combined-cycle power plants are much more thermally efficient than coal or nuclear plants – meaning they need less water for cooling. Such plants also have much less of an impact on the quality of the local water supply than coal or nuclear plants using the same cooling technologies.

"However, continued ramp-up of hydrofracking could greatly diminish the net water advantages of power plants that use natural gas. While power plant water use is much larger per unit of electricity potentially generated using natural gas from hydrofracking, water quantity – and quality – issues are still important to consider, particularly in the vicinity of hydrofracking operations.

"For example, the U.S. Environmental Protection Agency (EPA) estimates that some 35,000 hydrofracking wells used 70 billion to 140 billion gallons of water in 2011.

"Depending on the type of well and its depth and location, a single well can require 3 million to 12 million gallons of water when it is first drilled and fracked – many times the amount used in conventional vertical drilling. And operators use similar amounts of water each time they give a well a "work-over" to maintain pressure and gas production.

"A typical shale gas well will undergo two work-overs during its life span. Withdrawing these amounts of water over a short period of time can strain local water supplies, especially in arid and drought-prone regions in the West such as Texas.

"Hydrofracking for natural gas in Texas alone could require some 50 billion gallons of water in 2020. And unlike much of the water withdrawn for cooling power plants, most water used for hydrofracking is not recoverable because it stays in the wells.

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[8] Union of Concerned Scientists, July 2013, 'Water-Smart Power: Strengthening the U.S. Electricity System in a Warming World', www.ucsusa.org/clean_energy/our-energy-choices/energy-and-water-use/water-smart-power.html

"Hydrofracking can also affect water quality, because of improper well drilling and insufficient protection of drinking water aquifers. An EPA study identified more than 1,000 chemicals used in fracking.

"Many are considered harmless, but others, such as benzene, lead, and methanol, are toxic. A 2011 study identified another 29 of these chemicals as carcinogens. And a Cornell University study found that, of 353 chemicals used in hydrofracking and examined in the study, 25 percent cause cancer or other mutations, and about half could severely damage neurological, cardiovascular, endocrine, and immune systems. Industry attempts to reuse more water recovered from wells, or to use saline water rather than fresh, may lessen some of the effects of hydrofracking on both water quantity and quality."

A 2014 Bloomberg article discusses radioactive waste issues associated with fracking in the US. It states, in part:[9]

"Oilfields are spinning off thousands of tons of low-level radioactive trash as the U.S. drilling boom leads to a surge in illegal dumping and states debate how much landfills can safely take. ...

"Left to police the waste, state governments are increasing their scrutiny of well operators. Pennsylvania and West Virginia are revising limits for acceptable radiation levels and strengthening disposal rules. North Dakota's doing the same, after finding piles of garbage bags filled with radioactive debris in an abandoned building this year. ...

"The waste is a byproduct of the drilling renaissance that has brought U.S. oil and natural gas production to its highest levels in three decades – while also unlocking naturally occurring radium from rock formations far underground. ...

"The issue is shale rock, the dense formations found to hold immense reserves of gas and oil. Shale often contains higher levels of radium – a chemical element used in industrial X-ray diagnostics and cancer treatments – than traditional oil fields, [professor of geochemistry Avner] Vengosh said.

"Freeing gas and oil is a water-intensive process called hydraulic fracturing, or fracking, in which drill bits cut thousands of feet through shale fields to make way for high-pressure water streams that pulverize the rock. The process displaces radium-tinged subterranean water that comes up through the wells, where it can taint soil and surface equipment. Radiation levels can build up in sludges at the bottom of tanks, pipeline scale and other material that comes in extended contact with wastewater.

"Some states allow the contaminated material to be buried at the drill site. Some is hauled away, with varying requirements for tracking the waste. Some ends up in roadside ditches,

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[9] Alex Nussbaum, 17 April 2014, 'Radioactive waste booms with fracking as new rules mulled', www.bloomberg.com/news/articles/2014-04-15/radioactive-waste-booms-with-oil-as-new-rules-mulled

garbage dumpsters or is taken to landfills in violation of local rules, said Scott Radig, director of the North Dakota Health Department's Division of Waste Management.

"In that state's Bakken oilfields, "it's a wink-and-a-nod situation," said Darrell Dorgan, a spokesman for the North Dakota Energy Industry Waste Coalition, a group lobbying for stricter rules. "There's hundreds of thousands of square miles in northwestern North Dakota and a lot of it is isolated. Nobody's looking at where all of it is going."

"That's one of the problems the state is trying to fix with rules announced last week requiring well operators to install leak-proof containers for temporary storage onsite and to use licensed waste haulers and landfills. North Dakota, the biggest oil-producing state after Texas, has commissioned a study of radiation risks that may spur further changes, Radig said.

"In the meantime, North Dakota landfills have installed radiation detectors to try to catch loads exceeding the state's current limits. Anything higher must be trucked hundreds of miles to dumps in neighboring states that have less restrictive limits.

"On Feb. 28, North Dakota officials found hundreds of radioactive "filter socks" – used to strain wastewater from wells – dumped in an abandoned building in Noonan, just south of the Canadian border. The filters registered about 40 microrems an hour of radiation, about five times the naturally occurring "background level" in the area, Radig said.

"North Dakota wells may produce 27 tons a day of filter socks alone, Radig said, citing a private hauler's estimate. While most material is handled properly, it's "clearly not enough. There is definitely some illegal dumping going on."

The state hired a contractor last week to remove the Noonan filter socks. The operation will cost about $13,000 and use money from an industry-backed fund to clean up abandoned oil and gas wells, according to a Health Department statement.[10] *...*

"Pennsylvania allows producers to bury some waste onsite in lined pits. It's drafting rules to discourage that as a permanent option ... Further changes could come after Pennsylvania completes a study[11] *of radiation risks that's looking at everything from worker safety at the wellhead to allowable levels in landfills. Results are due later this year ..."*

Recycling of fracking waste can reduce water use and pollution from the wells, but it may generate a waste stream requiring management and disposal as Low Level Radioactive Waste. This issue is discussed in a 2016 U.S. Public News Service article:[12]

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[10] www.ndhan.gov/data/mrNews/2014-04-08-Noonan%20CleanUp-v.FINAL.pdf

[11] www.portal.state.pa.us/portal/server.pt/community/oil___gas_related_topics/20349/radiation_protection/986697

[12] Dan Heyman / Public News Service, 14 April 2016, 'Hot Sludge: Problems With Recycling Frack Waste', www.publicnewsservice.org/2016-04-14/environment/hot-sludge-problems-with-recycling-frack-waste/a51393-1

"Recycling of fracking waste can reduce water use and pollution from the wells, but only by creating low-level nuclear waste too hot for landfills. One fracking-waste recycler is operating near Fairmont and another is planned for Doddridge County. They take the brine, mud and drill cuttings from the wells and extract clean water and salt. The problem is that the uranium and radium that occur naturally underground get concentrated in the remaining sludge.

"Avner Vengosh, professor of geochemistry and water quality at Duke University has studied the hot sludge. "Once you concentrate all the radioactivity in sludge, the level will be very high," he said. "Something that you need to dispose in only designated low-radioactive-waste disposal sites."

"The recyclers proudly point out that the clean water can be reused by the drillers and the salt can be sold for deicing roads. And they say recycling will reduce the need for waste-disposal injection wells. They have not made clear what they plan to do with the sludge.

"In February, Kentucky state officials warned that state's landfills not to take what are known as technologically enhanced, naturally occurring radioactive material (TENORM). Twelve hundred cubic yards of sludge from Fairmont Brine Processing had been illegally buried in a landfill there last fall. No one from the Fairmont company returned a call requesting comment.

"Vengosh stresses that TENORM can be buried in such a way that it is disposed of safely. But he said the radioactivity is high enough to leech out of a regular municipal landfill. "If it's isolated, sure, it doesn't matter," he said. "But it would be a hundred times what we see in produced water and flow-back water, which is high by itself."

"Vengosh said the issue of naturally occurring radioactive waste is not unique to fracking, that other oil and gas wells in West Virginia probably also produce it. He said some of the hot elements in TENORM can have a half-life of a thousand years, and even after that the sludge is probably not safe. "Some of the secondary, or daughter or granddaughter isotopes coming from the decay are extremely toxic by themselves," he added. "The radioactivity would generate a legacy that could be over thousands of years.""

Even without recycling – and its attendant benefits, as well as problems such as concentration of radioactivity – radiation levels of fracking waste water can vary dramatically, as discussed in a 2014 article in the UK Independent:[13]

"Cuadrilla, the fracking company responsible for a series of earth tremors around Blackpool in 2011, has withdrawn applications for permits to frack in Lancashire after problems surfaced relating to the disposal of radioactive waste. Hydraulic fracturing – or fracking – releases gas or oil from shale by blasting a mixture of sand, chemicals and water into the rock. The process produces huge amounts of waste water that contains, among other things,

[13] The Independent, 27, Jan 2014, www.independent.co.uk/news/uk/home-news/caudrilla-withdraws-applications-to-frack-in-lancashire-after-encountering-problems-with-radioactive-waste-disposal-9088986.html

low-level naturally-occurring radiation. Industry regulator, the Environment Agency, has said that it will not grant a radioactive substances permit until it is sure that the water would be disposed of safely.

"When Cuadrilla fracked near Blackpool it found traces of naturally occurring uranium and thorium, as well as levels of radium that were 90 times higher than naturally occurs in drinking water. Previously, regulations classed the waste water as industrial effluent, allowing Cuadrilla to pour two million gallons into the Manchester Ship Canal after being processed at the Davyhulme treatment works at Trafford.

"However, "flowback water" has been re-classified as radioactive waste following European regulations which came into force in October 2011. This means the operator now needs a permit to safely dispose of the waste."

Likewise, Marvin Resnikoff from the Radioactive Waste Management Associates notes in a US report that "some shale gas deposits contain as much as 30 times the radiation that is found in normal background."[14]

Generally radioactive waste can either be treated as conventional waste (e.g. buried on site or sent to landfill) or it might meet the radiological criteria requiring management as Low Level Radioactive Waste (requiring a dedicated, licensed radioactive waste repository). West Virginia has pursued a third option: it has passed a law to segregate drill cuttings within landfills.[15] Presumably the waste in question does not meet the criteria for classification as Low Level Radioactive Waste. This issue is discussed in a 2014 Bloomberg article:[16]

"In West Virginia, on the edge of the gas-rich Marcellus formation, lawmakers voted last month to require landfills to install radiation monitors and to build separate, lined cells designed to contain drilling debris. The law[17], signed by Governor Earl Ray Tomblin March 31, also expanded the amount of oil and gas waste landfills can accept.

"With proper precautions, landfills are the safest place for the debris, said Thomas Aluise, a spokesman for the state Department of Environmental Protection. "A lot of operators were just burying them onsite, unchecked, all over the state," he said.

"While it's unclear how much drilling waste is produced nationally, state totals are rising. West Virginia landfills accepted 721,000 tons of drilling debris in 2013, a figure that doesn't

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[14] Dr Marvin Resnikoff / Radioactive Waste Management Associates, 10 January 2012, 'Radon in Natural Gas from Marcellus Shale', http://energyindepth.org/wp-content/uploads/marcellus/2012/04/Resnikoff.pdf

[15] 9 July 2014, 'Another complication for fracking - radioactive waste', www.dailyclimate.org/t/3930612887956560690

[16] Alex Nussbaum, 17 April 2014, 'Radioactive waste booms with fracking as new rules mulled', www.bloomberg.com/news/articles/2014-04-15/radioactive-waste-booms-with-oil-as-new-rules-mulled

[17] www.legis.state.wv.us/Bill_Status/bills_text.cfm?billdoc=hb107%20ENR.htm&yr=2014&sesstype=1X&i=107

include loads rejected because they topped radiation limits. The per-month tonnage more than tripled from July 2012, when records were first kept, through last December.

"In Pennsylvania, epicenter of the Marcellus boom, the oil and gas industry sent 1.3 million tons to landfills last year. That included 16,000 tons of radioactive material, according to Lisa Kasianowitz, a spokeswoman for that state's Department of Environmental Protection."

A number of jurisdictions require a permit or licence to manage Naturally Occurring Radioactive Materials arising from gas or oil fracking.[18] For example the UK requires a permit. In Sweden, the handling of radioactive shales requires a permit in accordance with the Radiation Protection Act and the Radiation Protection Ordinance when the uranium content exceeds 80 parts per million. This permit is granted by the Swedish Radiation Safety Authority and non-compliance can lead to it being revoked and, if done intentionally, the responsible person can be fined or imprisoned.[19]

4. ILLEGAL DUMPING

A few specific examples of illegal dumping of fracking waste are noted below, for illustrative purposes, but these are not isolated examples – a 2014 *Bloomberg* article discusses a "surge in illegal dumping" in the US and the efforts of state governments to stem the tide.[20]

A business owner and his two firms – fined millions of dollars after being accused of illegally dumping low-level nuclear waste – all filed for bankruptcy in a US federal court in March 2017.[21] Advanced TENORM Services, BES and Cory David Hoskins filed separate voluntary petitions for Chapter 7 bankruptcy on March 10, 2017. Advanced TENORM and Hoskins were each fined US$2.65 million by the Kentucky Cabinet for Health and Family Services in November 2016 for dumping out-of-state radioactive waste in landfills in Estill and Greenup counties in Kentucky. Officials say the waste was a by-product of fracking and had been transported from Ohio, West Virginia and Pennsylvania in 2015.

North Dakota was the site of another example of illegal dumping:[22]
"North Dakota recently discovered piles of garbage bags containing radioactive waste dumped by oil drillers in abandoned buildings. Now, the state is trying to catch up to an oil industry that produces an estimated 27 tons of radioactive debris from wells daily. Existing

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[18] David Lowry, January 2015, 'Fracking's hidden hazard of gender-bender chemicals and radiation risks', http://drdavidlowry.blogspot.co.uk/2015/01/frackings-hidden-hazard-of-gender.html
[19] David Lowry, January 2015, 'Fracking's hidden hazard of gender-bender chemicals and radiation risks', http://drdavidlowry.blogspot.co.uk/2015/01/frackings-hidden-hazard-of-gender.html
[20] Alex Nussbaum, 17 April 2014, 'Radioactive waste booms with fracking as new rules mulled', www.bloomberg.com/news/articles/2014-04-15/radioactive-waste-booms-with-oil-as-new-rules-mulled
[21] Associated Press, 14 March 2017, 'Companies file for bankruptcy after radioactive waste fines', www.usnews.com/news/best-states/kentucky/articles/2017-03-14/companies-file-for-bankruptcy-after-radioactive-waste-fines
[22] Climate Progress, 16 April 2014, 'North Dakota Finds Itself Unprepared To Handle The Radioactive Burden', http://thinkprogress.org/climate/2014/04/16/3427345/north-dakota-radioactive-waste-fracking/

fines have apparently not been enough to deter contractors from dumping oil socks – coiled filters that strain wastewater and accumulate low levels of radiation. The state is in the process of drafting rules, out in June, that require oil companies to properly store the waste in leak-proof containers. Eventually, they must move these oil socks to certified dumps. However, North Dakota has no facilities to process this level of radioactive waste. According to the Wall Street Journal, the closest facilities are hundreds of miles away in states like Idaho, Colorado, Utah, and Montana."

In Australia, the Environment Protection Authority took almost a year to issue a $1500 fine to energy company Santos in 2014 over contamination of an aquifer near a major coal seam gas project, which included uranium at a level 20 times the Australian drinking water guideline for human health.[23] The fine was a small fraction of the maximum possible $1 million fine.

The Fairfax press reported that the investigation was sparked in March 2013 after Santos informed the EPA that routine testing of groundwater at the project detected ''elevated levels'' of naturally occurring elements. It concluded the contamination was caused by water leaking from a pond used to hold waste water when gas is extracted from wells. The pond was poorly constructed by the project's previous owner, Eastern Star Gas. Test results commissioned by Santos showed lead, aluminium, arsenic, barium, boron, nickel and uranium at levels ''elevated when compared to livestock, irrigation and health guidelines''. The uranium level detected was 335 micrograms per litre − about 20 times the Australian drinking water guideline for health of 17 micrograms per litre.[24]

5. SHALE GAS AND RADON EXPOSURE

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[23] SMH, 10 March 2014, 'EPA defends its actions over 'natural' uranium in contaminated aquifer', www.smh.com.au/environment/water-issues/epa-defends-its-actions-over-natural-uranium-in-contaminated-aquifer-20140309-34fhp.html
See also:
www.epa.nsw.gov.au/epamedia/EPAMedia14021802.htm
www.theaustralian.com.au/business/business-spectator/santos-gas-game-shattered-by-a-ubomb/news-story/e3878f7807c2a01a27181ffe3635d2c4
www.abc.net.au/news/2014-03-12/environmentalists-alarmed-at-coal-seam-gas-contamination-scare/5315926
www.theage.com.au/environment/coal-seam-gas-epa-tells-santos-to-keep-tabs-on-pilliga-radioactive-water-20140311-34kf7.html
www.smh.com.au/environment/santos-coal-seam-gas-project-contaminates-aquifer-20140307-34csb.html
www.theguardian.com/world/2014/mar/08/santos-fined-coal-seam-gas-contaminates-aquifer-uranium
www.echo.net.au/2014/03/pilliga-contamination-sparks-calls-halt-csg-industry/
http://dea.org.au/news/article/media-release-doctors-alarmed-by-water-contamination-from-unconventional-ga
[24] SMH, 10 March 2014, 'EPA defends its actions over 'natural' uranium in contaminated aquifer', www.smh.com.au/environment/water-issues/epa-defends-its-actions-over-natural-uranium-in-contaminated-aquifer-20140309-34fhp.html

The UK Nuclear Free Local Authorities, in a 2013 paper on shale gas and fracking, discusses whether the inhalation of radioactive radon gas in shale gas pose serious health risks[25]:

"Shale gas, unlike gas from oil and gas wells, contains radioactive radon gas. (In fact, oil and gas wells do contain some radon but shale gas contains much higher concentrations.) This arises from radioactive decay of uranium minerals found in all shale formations. Radon is chemically inert and cannot be separated from shale gas. This means that when shale gas is piped into boilers, ovens, hobs and other gas appliances in homes and burnt, radon gas is released into indoor areas.

"Radon is a recognised public health threat, and the Health Protection Agency (HPA) has issued guidance stating the existing homes should be remediated where radon levels reach 200 Bq per cubic metre. For new homes, the target is 100 Bq per cubic metre.

"High indoor radon concentrations from shale gas are already a serious health problem in parts of the United States including New York City. The vital parameters are the concentrations of uranium in shale formations; the consequent radon concentrations in shale gas; and the time delay from extraction to delivery in homes. According to a parliamentary reply to a recent PQ from Paul Flynn MP, the Government has requested the Radiation Protection Division of the HPA to urgently examine this matter and to prepare a report for Ministers. When this is published, the NFLA Secretariat will issue a summary for NFLA members. The NFLA Secretariat is keeping this matter under close review."

British environmental consultant Dr David Lowry noted in a 2014 paper:[26]

"One conclusion in the report published in March this year by the public health watchdog, Public Health England, in their Review of the Potential Public Health Impacts of Exposure to Chemical and Radioactive Pollutants as a Result of Shale Gas Extraction[27], states: 'If the natural gas delivery point were to be close to the extraction point with a short transit time, radon present in the natural gas would have little time to decay ... there is therefore, the potential for radon gas to be present in natural gas extracted from UK shale.'

"Radon is unquestionably the leading cause of lung cancer in non-smokers.

"Moreover, Professor, James W. Ring, Winslow Professor of Physics Emeritus, Hamilton College in New York State stresses: "The radon and natural gas coming from the shale mix together and travel together as the gas is piped to customers. This is a serious health hazard,

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[25] NFLA Briefing No.103, 30 Jan 2013, 'Shale Gas and Fracking: An Energy Solution or an Environmental Nightmare?', www.nuclearpolicy.info/docs/briefings/A219_(NB105)_Shale_gas_fracking.pdf

[26] David Lowry, January 2015, 'Fracking's hidden hazard of gender-bender chemicals and radiation risks', http://drdavidlowry.blogspot.co.uk/2015/01/frackings-hidden-hazard-of-gender.html

[27] Public Health England (formerly the Health Protection Agency), 30 October 2013, 'Shale gas extraction: review of the potential public health impacts of exposures to chemical and radioactive pollutants (draft for comment)', Part of: Radiation: PHE-CRCE report series www.hpa.org.uk/webc/HPAwebFile/HPAweb_C/1317140158707

as radon – being a gas – is breathed into the lungs and lodges there to decay, doing damage to the lung's tissue and eventually leading to lung cancer."[28]

"Hence there is undoubtedly a risk of radon gas being pumped into citizens' homes as part of the shale gas stream. Unless the gas is stored for up to a month to allow the radon's radioactivity to naturally reduce, this is potentially very dangerous (a half-life of 3.8 days – using the general rule of thumb of 10 half-lives to decay to 1/1000 of original concentration, that would be 38 days, or roughly one month, depending on how radioactive it was to start)."

In another paper Dr Lowry summarises some of the relevant research:[29]

"The current concern about how much radon is likely to be piped into people's kitchens was spurred by a report last year by Dr Marvin Resnikoff, of Radioactive Waste Management Associates (http://rwma.com/aboutus.htm). Dr Resnikoff estimated radon levels from the Marcellus gas field – the nearest one being exploited to New York – as up to 70 times the average. Dr Resnikoff's group, now based in Vermont, used be to be based in Brooklyn, New York, hence its work on shale gas being piped to New York consumers. RWMAs suggest some shale gas deposits contain as much as 30 times the radiation that is found in normal background.(http://gdacc.org/2012/01/10/radon-in-natural-gas-from-marcellus-shale-by-marvin-resnikoff-radioactive-waste-management-associates/). New scientific evidence on these concerns was published in the US journal Environmental Science & Technology in September 2013 ("Impacts of Shale Gas Wastewater Disposal on Water Quality in Western Pennsylvania," http://pubs.acs.org/doi/abs/10.1021/es402165b).

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[28] www.hamilton.edu/index.cfm

[29] David Lowry, 13 May 2014, 'Radon risk distorted by pro-fracking Lords report', http://drdavidlowry.blogspot.co.uk/2014/05/radon-risk-distorted-by-pro-fracking.html