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ABSTRACT

The presence of NORM (Naturally Occurring Radioactive Materials) in the oil and gas industry is well documented. Specifically, radium isotopes such as 226Ra and 228Ra are present. The process of bringing oil to the surface has the unintended consequence of enriching the level of radioactive radium on these sites because barium and calcium salts are replaced by the chemically similar radium. These low-level radioactive materials represent a small but potentially significant health risk for workers in the industry. While short exposures are hypothesized to be harmless, exposures over long periods of time have potential health consequences. From our previously published results, we have found NORM in high concentrations in several sites in west Texas in samples from soil, pipes, and tank sludge. This represents a potential environmental health hazard for the workers in these sites and in the industry in general. Here we calculate approximate yearly dosages over the course of a typical worker's time spent on the field. In addition, we evaluate the local, state, and federal environmental health response to this hazard in terms of communication, prevention, and responsiveness, and make policy, outreach, and educational recommendations.

Keywords: NORM, environmental health, public health, radiation occupational hazard, gas and oil industry, Texas, 26Ra and 228Ra

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Introduction

The quest for energy efficiency goes back to the beginning of the industrial revolution and the days of coal supremacy but it has reached an unprecedented level of urgency and geopolitical significance with two seminal events; the invention of the internal combustion engine and the discovery of easily accessible and at the time seemingly inexhaustible oil supplies in the Middle East. More recently, technological advances in oil extraction from formerly inaccessible but vast sources such as shale have generated tectonic shifts in these energy and geopolitical considerations. In 2016, the United States imported 10.1 MMbl/day of petroleum with the top five countries of origin being Canada (38% of imports), Saudi Arabia (11%), Venezuela (8%), Mexico (7%), and Colombia (5%). [1]. By contrast those imports were higher by 36% at 13.71 MMbl/day ten years earlier in 2006 while exports at the time were four times lower (1.32 MMbl/day in 1996 vs.5.22 MMbl/day in 2006). A review of data pertaining to U.S. petroleum production, imports, exports, and consumption for the last 57 years from the U.S. Bureau of Transportation Statistics paints the same picture, i.e., one of increasing demand, production and export of petroleum products and a concurrent reduction on the reliance of imports from other countries especially ones from troubled spots around the globe [2]. Table 1 and Figure 1 below summarize these observations for a time period exceeding the last half century.

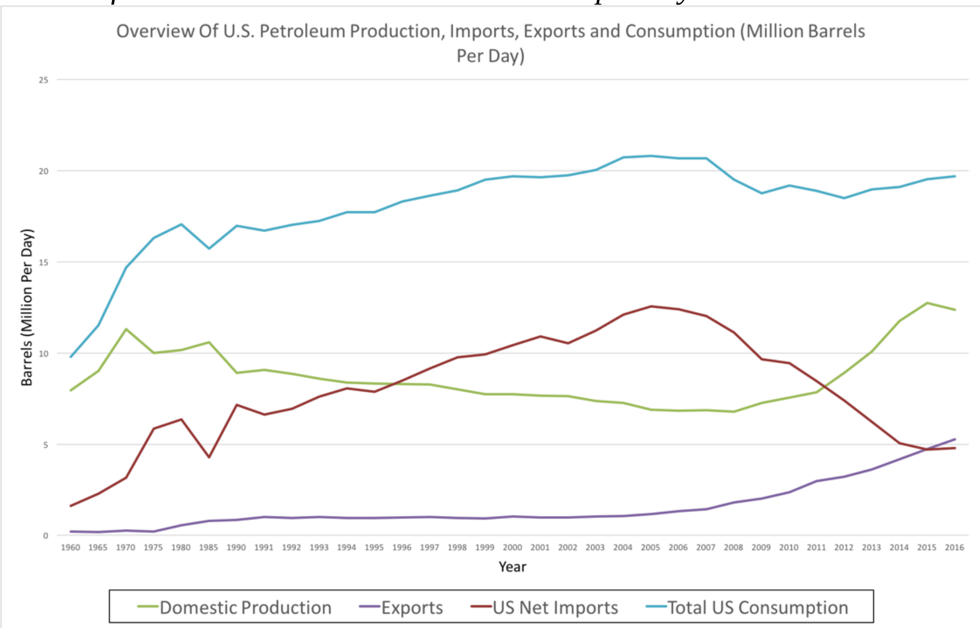
Table 1. *Total Production, Imports, Exports, and Consumption of Oil in the U.S. from 1960 to 2016 in Million Barrels per day*

	Total domestic U.S. production	**Total U.S. net imports**	**Total U.S. exports**	**Total U.S. consumption**
Year				
1960	7.96	1.61	0.20	9.80
1965	9.01	2.28	0.19	11.51
1970	11.30	3.16	0.26	14.70
1975	10.01	5.85	0.21	16.32
1980	10.17	6.36	0.54	17.06
1985	10.58	4.29	0.78	15.73
1990	8.91	7.16	0.86	16.99
1991	9.08	6.63	1.00	16.71
1992	8.87	6.94	0.95	17.03
1993	8.58	7.62	1.00	17.24
1994	8.39	8.05	0.94	17.72
1995	8.32	7.89	0.95	17.72
1996	8.29	8.50	0.98	18.31
1997	8.27	9.16	1.00	18.62
1998	8.01	9.76	0.94	18.92
1999	7.73	9.91	0.94	19.52
2000	7.73	10.42	1.04	19.70
2001	7.67	10.90	0.97	19.65
2002	7.62	10.55	0.98	19.76
2003	7.37	11.24	1.03	20.03

2004	7.25	12.10	1.05	20.73
2005	6.90	12.55	1.16	20.80
2006	6.83	12.39	1.32	20.69
2007	6.86	12.04	1.43	20.68
2008	6.78	11.11	1.80	19.50
2009	7.26	9.67	2.02	18.77
2010	7.55	9.44	2.35	19.18
2011	7.86	8.45	2.99	(R) 18.89
2012	(R) 8.90	7.39	3.20	18.49
2013	10.07	6.24	3.62	(R) 18.97
2014	(R) 11.77	5.07	4.18	(R) 19.10
2015	(R) 12.75	4.71	4.74	19.53
2016	12.37	4.79	5.26	19.69

Note: these numbers include later revised figures, designated as (R), for years 2012, 2014, and 2015 for the production column and for years 2011, 2013, 2014 for the consumption column

Figure 1. *Overview of Production, Imports, Exports and Consumption of Oil in the U.S. from 1960 to 2016 in Million Barrels per day*



The exploration and exploitation of these sites alongside more traditional oil sources has intensified the environmental and public health concerns associated with these commercial activities. Specifically, eight years after the discovery of radioactivity by Henri Bequerel in 1986 it was shown that oil and natural gas also contain radioactive deposits. While this presence went largely ignored for decades, an influx of research in the 1980s sought to characterize and quantify these deposits. For example, scrap metal dealers started detecting abnormally high levels of radiation from oilfield piping that was found to be due to the presence of ^{226}Ra [1]. In 1991, an article was published on the new 'hot' wastes in NORM and in 1992, the health physics aspects of radioactive petroleum piping scale were described [3, 4]. NORM will develop in high concentrations in by-product oil and gas waste streams [5, 6, 7, 8]. The NORM will chemically separate from other piped material in the process of the extraction of oil, resulting in high concentrations of ^{226}Ra and ^{228}Ra, and other daughter product radioisotopes such as ^{210}Pb in a densely caked layer on the inner surfaces of the piping [9]. The activity of ^{226}Ra in this NORM ranges from 0.185 to several thousands of Becquerels per gram (Bq/g) of sample depending on the geological formation where the oil reserves are found. By comparison, the NORM concentrations of radium in rock and soil are, at a natural level, in the range of 0.018 5–0.185 Bq/g [9].

The presence of NORM necessitates the disposal of contaminated material in the interest of public health especially the health of oil field workers. Several methods exist to accomplish that task and the major two, dispersal along the surface of the industrial site or removal and storage depend on the concentration of the radioactivity. One could argue that the dispersal method itself is problematic too because long-term exposure to low levels of radioactivity has the potential to cause health problems such as increased incidences of cancer. By its nature, this radiation source can safely be assumed to be ineffective on short-term workers, visitors and the general public. However, workers who remain on such sites for the entire workday and possibly for many years on end constitute a particularly vulnerable group whose health concerns should be taken into account. The fact that exposure to low level radiation has a stochastic effect in diseases such as cancer and others makes the exact calculation if its effects difficult and contributes to practices not entirely geared towards benefiting public health. This method is the preferred one in many oil and gas sites including those found in Texas due to its simplicity and low cost. The second method is more expensive and very often involves the complete removal of a layer of top soil from the site and its transfer to a storage facility. For many such sites in Texas, it is less expensive to simply remove the top layer and have it shipped to neighboring states (e.g. Oklahoma) where it is simply stored as exposed piles of dirt. This common practice is again the outcome of reduced cost, i.e., it is cheaper to load this material on trucks, have it transported in average a couple of hundred miles and dumped than it would otherwise be, should the industry have to invest on storage sites according to specifications. It should be emphasized here that the United States is a federal country where each state produces its own legislation in addition to an overarching umbrella of federal legislation. Environmental, public health, occupational health, and other legislation fit exactly into this complex arrangement. This state of affairs has the unintended consequence of generating monetary incentives in cases such as the disposal of NORM found on gas and oil industrial sites where the legislatively mandated disposal in circumvented by quite literally “dumping” the problem on a neighbor. It should be emphasized here that transporting environmentally hazardous material from one area of exposure to another one does not alleviate a public health concern. The area of the body most likely to be affected by contaminated food and water intake is the skeleton due to the similar (same group on the periodic table) chemical properties of radium and calcium. The main radioisotopes of concern here are^{226}Ra and ^{228}Ra, an alpha and a beta emitter respectively. In terms of cellular targets, it is known that proliferating ones tend to be less radiosensitive than quiescent ones.

Methodology

Organizations and Websites

Data form a variety of sources such as the U.S. Energy Information Administration, the U.S. Bureau of Transportation Statistics, The Center for Disease Control and Prevention (CDC), the Environmental Protection Agency, the *Food and Drug Administration (FDA)*and their websites were explored for information such as the import and export of petroleum products and their relative and absolute levels for the last half-century and policies related to NORM exposure [10,11,12].

Disposal of NORM becomes more problematic as higher concentrations of guidelines for different radionuclides in drinking water to be at a limit of 0.185 Bq/L. These guidelines were set so that all water systems could meet health standards without creating a financial burden to the towns and counties with the potentially contaminated water arising from NORM. The Texas Commission on Environmental Qualityis in charge of monitoring radium in the drinking water systems throughout the state [13]. Both water testing and enforcement of any violations that may occur fall within their mandate. The radionuclides of most interest in Texas drinking water are ^{226}Ra and ^{228}Ra, which emit alpha and beta particles, respectively, along with their associated gamma emissions including their daughter products. Radium is efficiently absorbed into the human body, with intake by way of food and water as a chemical analogue of calcium, and is incorporated into bones. There it can potentially cause an array of health effects including bone sarcoma, leukemia, cancer of the mastoid and paranasal sinuses, cancer of the upper digestive tract and orofacial cleft [14].

The EPA has also placed a limit of 1.11 Bq/g for radioactivity found in contaminated soil. The obvious concern here, aside from any direct exposure, is that any elevated concentrations in radionuclides in soil may eventually leach into the groundwater.

Results

CDC

The Center for Disease Control and Prevention (CDC) headquartered in Atlanta, Georgia, is tasked with the protection of Americans from health, safety and security threats. According to its mission statement “whether diseases start at home or abroad, are chronic or acute, curable or preventable, human error or deliberate attack, CDC fights disease and supports communities and citizens to do the same. CDC increases the health security of our nation. As the nation’s health protection agency, CDC saves lives and protects people from health threats". Given the large scope this mission entails and the well-documented work the CDC has done to protect the citizenry from diverse threats such as viral and bacterial diseases (e.g. influenza), chronic ailments (e.g. heart disease) and others (e.g. epilepsy) it comes as no surprise that it contains guidelines for exposure to radioactive material. However, unlike other areas of health concern where clear instructions to professionals and the public exist, the radioactive contamination danger is underrepresented in its overall regulatory and public outreach literature. For example, the CDC offers guidelines for cell phone radiation exposure, information for radioactivity present in building materials, and radiation emergency training, education and tools as part of its emergency and preparedness response plan [15, 16, 17]. Absent however, from these worthwhile public safety concerns are any provisions for exposure to NORM and uptake of radioisotopes originating in the oil and natural gas industry.

EPA

In recent years the use of horizontal drilling known as "fracking" has resulted in increased volumes of radioactivity from NORM sources and the resulting exposure on workers and others [18, 19]. While this practice has had a beneficial economic impact, diversifying worldwide sources of oil, and decreasing reliance on oil imports from politically unstable regions, there have been a number of unforeseen negative consequences such as increased seismic activity. The increased oil and gas output has also resulted in an increase in NORM produced. The EPA provides information on the basics of radiation, how to protect from exposure, laws and regulations, and response guidelines in case of radiological accidents [20]. Absent however from this body of federal oversight is a more direct requirement to provide annual quantitative information on transport of TENORM (Technologically Enhanced Naturally Occurring Radioactive Material) at the state level.

Food and Drug Administration (FDA)

The FDA disseminates a plethora of regulatory information regarding radioactive materials. Due to its specific mission, the FDA is primarily concerned with radioactive drugs and pharmaceuticals and an initiative to reduce unnecessary radiation exposure from medical imaging [21]. No such initiative exists for NORM in the oil and gas industry which is understandable. However, we propose that this initiative can serve as a model for the reduction of radiation exposure from NORM and the practices the oil and gas industry must undertake in order to affect this guideline.

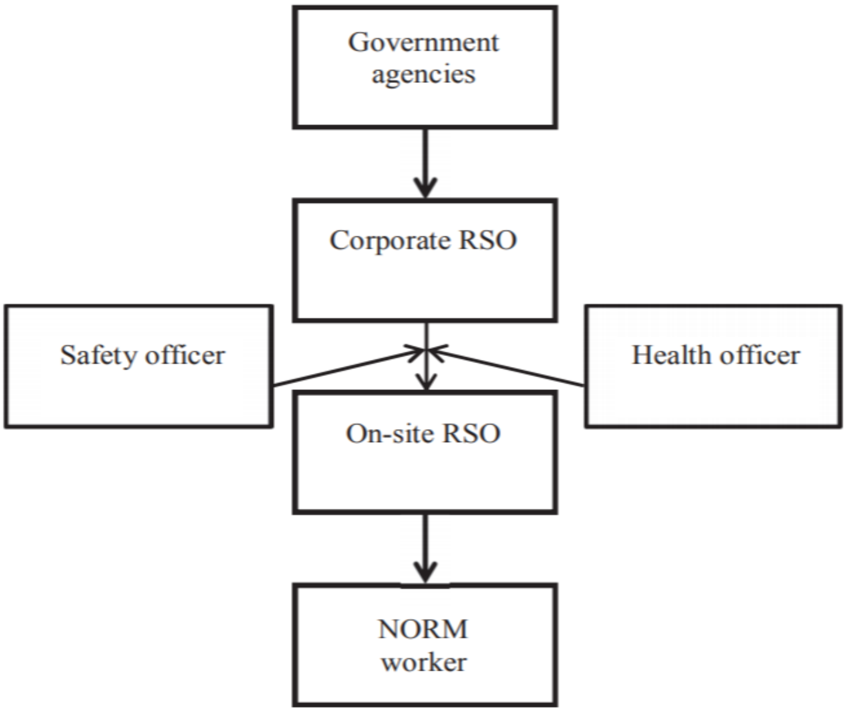
NORM Awareness Training [22]

Given the possible adverse effects of NORM contamination on health and its increasing incidence, several sites and agencies currently offer training on NORM awareness. Environklean Product Development Inc. (EPDI), a Texas company based in Houston, specializes in services for the onshore and offshore energy industry. Part of those services include specialty chemical manufacturing and NORM decontamination and consulting. EPDI offers a series of NORM safety courses for tits employees and to employees of other companies especially those workers in the oil and gas exploration industry. [23]. This training is not only limited to employees directly dealing with the NORM or who are present on the field. It is also beneficial for employees in management positions to have training in health and safety and to be aware of current regulations. It is a valuable resource for other companies in the oil and gas field to have their employees trained in NORM awareness so that they understand the risks and regulations of working with this part of the oil and gas industry. These other companies may then train other field or environmental workers as well as executives. Typically, a class of that kind needs to comprise a general introduction to radiation as well as worker safety and health concerns. This includes going back to the fundamentals of general chemistry, including explaining what an atom and its subatomic components are. Thus the theory provided includes information on protons, electrons, neutrons, radioisotopes, types of radiation (alpha, beta, gamma, etc.), island of stability, and concepts of exposure and dosage. Taking the extra time and care to go over the basics helps provide benefits in both health and safety and avoids any potential violations. Next, it is important to determine where the radiation in the oil and gas field comes from using decay series and visual aids. A general description of where NORM collects during the process is also useful.

One of the most important aspects in the training course is worker safety. This includes but is not limited to on-the-job site safety, emergency preparedness and personal protective equipment (PPE). The PPE varies depending on what the particular job entails and can includes fire retardant clothing, gloves, safety goggles, mask, steel toed boots, a thermo luminescent dosimeter badge, a hydrogen sulfide (H_2S) monitor, a hard hat and self-contained breathing apparatus. Stressing the importance of PPE is not only vital to the safety of the workers but important for adhering to state and national guidelines as well. This part of the training should ideally be ongoing and emphasized everyday by the radiation safety officer (RSO) of the job site. For example, forgetting to wear an H_2S monitor can lead to potentially serious health effects which can easily be prevented. It is mandatory for the onsite RSO to go over the safety guidelines for the specific job site each day. Greater precautions should be exercised with regard to closed container operations. The radionuclides, especially ^{222}Rn, tend to build up in the lower levels of the tanks or containers where a self-contained breathing apparatus is always necessary. The class also highlights the importance of monitoring for low levels of radiation each time someone leaves the restricted area. This method, called ‘frisking out’, is when the RSO on duty runs a pancake probe Geiger–Müller (GM) counter over the person’s body, focusing especially on the hands. If the readings are above background, the employee is required to wash the affected area and change clothes if necessary. This procedure is outlined with great importance in order to prevent accidental ingestion of radionuclides from the job site. Another imperative section of the training is the education pertaining to the health effects of NORM. Since all high doses of radionuclides can potentially cause damage, the class focuses on the four radionuclides that pose the most concern in the field: ^{226}Ra, ^{222}Rn, ^{228}Ra and ^{210}Pb. Emphasis is also placed on how NORM is indistinguishable from non-radioactive material. Providing pictures of scale and its buildup on pipes helps reinforce proper safety when dealing with these radionuclides. Explaining how radiation enters the human body is also a key point. Using a chart to describe the simplistic interactions between the gamma rays and alpha and beta particles is also advantageous. This supports the point that the highest risk of working with NORM comes from ingesting the radionuclides containing alpha and beta particles and helps highlight the necessity of using gloves and frisking out when working around this material.

The class ends with a review of the important facts followed by an examination of the material learned. After passing the test, employees can work with NORM knowing the proper procedures and protocols required for its handling. For new workers, it is important to stress the key facts learned during the course to ensure proper safety procedures. A refresher course for employees that have worked with NORM for a number of years is beneficial, since it is easy to become complacent and forget the safety aspects of NORM and its associated health effects. An overview of the implementation of these rules and regulations is depicted in Figure 2.

Figure 2. *Implementation of Rules and Regulations for NORM Workers and the Interplay between Government Agencies, Workers on NORM Sites, Safety Officers, Health Officers, and Corporate and on Site Radiation Safety Officers known as SROs*



Training at Different Levels of Education

A big hurdle in training for NORM in the oil and gas field in Texas is the wide array of academic backgrounds that one may come across among those taking the course. Often, the knowledge of NORM or radiation is limited. This then necessitates spending more time on the basics of radiation or even chemical science before the employees are able to understand properly the meaning of radiation and its effects. Taking the time to teach the individual class members the fundamentals helps them immensely to understand the class material. It is useful to show how a typical person interacts with low levels of radiation in their everyday life and that working with radioactive materials does not have to be a hazard, providing proper precautions are closely followed. Of great interest is the fact that the population of Spanish speaking residents is rapidly growing in Texas following a trend encountered in many other states as well that offer economic opportunities to this segment of the population. The need to train employees who are not fluent in English is thus becoming more common. During these classes, it is important to make sure that everyone follows the instructions. This is best accomplished by ensuring that there are bilingual people in the class who can help with translation. The training of employees with a non-scientific background also entails that they understand the importance of taking samples and correctly labelling them for further off-site analysis. Receiving samples that are improperly labelled or not labelled at all can be a major problem especially when dealing with radionuclides such as ^{222}Rn that have a short half-life. In order to get an accurate reading of radionuclides, it is important that the air samples be labelled with the date they were taken and length of sampling time. This portion of the training needs to be refreshed at least once a month to ensure that the employees adhere to proper sample protocols.

On-the-job Site Monitoring and Training

Each job site needs to be monitored at all times because of the nature of the NORM that is encountered during decontamination and is having to be cleaned up. On-the-job training may be necessary if a new or different situation is encountered. If this is the case, it is the responsibility of the RSO on the job site to help train and monitor the site. There may be a requirement for a portion of the actual job training to take place on site to better inform the employees. Hands-on training in addition to in-class instruction helps to reinforce the material being taught. Training workers on NORM is valuable for the health and safety of the employees in the oil and gas industry and for the general public. Refreshing all employees on the subjects they have learned will help create a safer work environment and minimize accidents. It is important to update and make changes to the ongoing training as new regulations and guidelines are put into effect. With the training course and proper on site job monitoring, the risks of working with NORM are greatly reduced, making it a safe working environment for all employees.

Discussion

The presence of NORM as a byproduct of oil and gas exploration constitutes an environmental and occupational health hazard that can affect adversely several groups of people. Included in these groups are the workers in the oil fields and the people living in communities surrounded by disposed soil from oil fields containing NORM. Oil is an indispensable part of the economy, provides a huge part of the energy needs and will continue to do so for the foreseeable future despite the advent of more ecologically friendly renewable sources. Here we have looked at one location, Texas USA, where oil production has traditionally been a key part of the economy to the extent of having been interwoven with the culture of the State. The practice of "fracking" has allowed the extension of oil discovery production to more sites while at the same time exacerbating the environmental footprint of this operation. The Texas commission on Environmental Quality provides information and resources on NORM such as the issuance of permits, cleanup and remediation and the reporting on problems but does not address the problem of transporting NORM contaminated soil to other states. The absence of quantitative data (e.g., percent transported versus percent stored in facilities) on how NORM contaminated material is disposed at the state level unnecessarily complicates the hazard NORM poses.

We have attempted to quantify the range of the annual dosage a worker will receive from working at an oil site in a typical West Texas location where the majority of oil and gas reserves are found. These dosages may be significantly higher in other regions of the world. That calculation represents the maximum exposure for a human being, given the fact that people exposed to NORM by virtue of the fact that they live near a disposal site containing NORM-contaminated soil would receive a much reduced dosage due to the protecting effect of having an increased distance from the source of the radioactivity. It should be noted here that these numbers constitute "ballpark" figures that serve as first approximations of the risk to people exposed to radiation. Three factors complicating a more precise calculation of risk are the following: first, the presence of complex geometry; the human body is not a precisely defined single geometric shape and the distance to the source of radiation can change at any time. Second, the same level of radiation can have very different effects on the various tissues and organs of the human body; generally speaking, the more a tissue regenerates the more radiosensitive it is. It is estimated that approximately two-thirds of the dose is absorbed by the skin [24]. Third, the risk of developing a neoplastic growth is a stochastic calculation from causes that are genetic or environmental such as smoking or being exposed to pollution and exposure to NORM is no exception.

We recommend the following three-step approach in dealing with this environmental hazard:

1. Increase public awareness of the environmental hazard NORM from the oil industry represents. This awareness should parallel steps already taken to inform the public of similar chemical hazards such as the presence of

lead or chromium in water. This publication is a step in that direction. The recommendation is to include this information as part of the Environmental and Occupational Health Science curriculum in colleges and universities and by increasing public awareness of the health hazard by the dissemination of seminars on the subject.

2. Initiate contact with people and leaders of communities where people are exposed to NORM from the oil and gas industry. This second recommendation is in direct follow up of the previous one. Success in this endeavor cannot be predicted but the authors feel that two factors will complicate its implementation. The first such factor has to do with the degree to which communities benefit economically from gas and oil industry operations. Communities whose members receive direct employment opportunities from the oil and gas industry are expected to be highly resistant to any form of regulation that could be perceived as jeopardizing their livelihood. By contrast, other communities whose members are not employed by the oil and gas industry but simply happen to live in places that serve as repositories for contaminated soil are expected to be much more receptive.
3. Encourage the introduction of State legislation that will seek to limit the practice of open storage of NORM. For example, many students and faculty from Health Science university departments attend policy trips to state legislatures where they are introduced to the lengthy and painstaking process of adapting legislation that affects the health of entire communities. These students and their professors can increase awareness of the NORM hazard among politicians through letter writing and through personal contacts when they visit State legislatures. In addition, those Health Science students who have found employment in State legislatures can be easily lobbied to act as intermediaries among university departments advocating for the aforementioned legislation and politicians who introduce bills.

Conclusions

There is a marked absence of detailed and uniform legislation, public health outreach, educational opportunities, and guidelines regarding the environmental health threat that NORM in the oil and gas industry poses. We propose that that an initiative is undertaken to educate the public about this issue and to enact change by means of seminars to health science educational programs (environmental health, public health, occupational health, and others) in the country. In addition, we propose the mobilization of public health and environmental and occupational health professionals in an attempt to influence legislative proposals that will fill in the existing legislative vacuum.

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