The Case for an Unconventional Natural Gas Development Health Registry

A White Paper Produced by the
Southwest Pennsylvania Environmental Health Project

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A prefatory note from the authors:

The Case for an Unconventional Natural Gas Development Health Registry grew out of the Southwest Pennsylvania Environmental Health Project's work with residents and communities on the Marcellus shale. As a result the report focuses on unconventional natural gas (not oil) extraction, processing and transport. Information on shale gas activity from research universities, regulatory agencies, and non-governmental organizations across the nation was, however, critical to the development of this report.

Our understanding of the activities surrounding shale resource development, and of the characteristics and composition of the shale, is constantly evolving. We are now aware that the exposures and resulting health effects from natural gas extraction are likely similar, or even identical to, that from unconventional shale oil.

As a result, the research on exposures and health risks and the discussion of registries can be read to include shale oil development as well as gas development.

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Executive Summary

Unconventional Natural Gas Development (UNGD), which includes hydraulic fracturing along with associated production, transport and waste disposal activity, is occurring in every region of the country. There is a growing body of air emissions data that the UNGD industry has submitted to state regulatory agencies and that researchers have been collecting and modeling. There is also an expanding account of water contaminants released during the UNGD process. It is, therefore, possible to know (or know estimates of) some of what is emitted at most points in the shale gas extraction, production and transport cycle. This is critically important because shale gas drilling, hydraulic fracturing, compressing, and processing are occurring very close to where people live and work and where children go to day care and school.

As shale gas development increases, so do reports of illness. Illnesses or conditions reported may be persistent, transient, intermittent, or potentially chronic. Symptoms such as burning eyes, headaches, rashes, and tingling or numbness in extremities are seen near UNGD sites across the country. Reports of these and many other symptoms have been documented by researchers associated with universities, public agencies and non-profit organizations.

Researchers have established two key components of the health effects landscape: 1) specific emissions that could plausibly be associated with reported health effects; and 2) health symptoms which seem to be relatively consistent across US shale plays. These two areas of research, the paper suggests, justify consideration of a UNGD health registry. A registry related to residents' exposures and/or health effects could inform practical on-the-ground public health interventions as well as serve long-term research and policy ends.

The paper consists of three parts. Part 1 (section 1) provides a brief summary of the extraction and processing of natural gas. It then presents a discussion of environmental releases from the UNGD process – water contamination and air emissions (section 2). The paper then reviews existing research on symptoms reported by individuals and the health consequences of some of the most consistently found UNGD emissions, those being VOCs and particulate matter (section 3).

Part 2 is devoted to registries. It discusses the benefits of registries generally, and it lays out different types of registries that can inform our thinking about a UNGD-related registry (section 4). It identifies three relevant types of registry: exposure registry, disease registry and disaster registry; and introduces a set of questions that can serve as a guide to thinking about the development of a UNGD health registry (section 5).

The final section of the paper (section 6) presents the outcomes of a two-day workshop on a UNGD registry attended by a national group of experts. Workshop participants focused on the need for, and challenges associated with, a registry. They converged around two potential starting points: 1) a rostering effort and 2) tapping into existing data collection activities.

The Case for an Unconventional Natural Gas Development Health Registry

Unconventional Natural Gas Development poses health risks to those living within the reach of its emissions. Meanwhile, comprehensive data on exposures and illness have been difficult to collect – limited more by policy decisions than technical obstacles. The data that have been collected on emissions and health effects, however, point to the value of a health registry.

A health registry can illuminate and define a public health problem – its risk factors, symptom profile, trajectory and scope. In so doing, it can inform policy, research and clinical practice. This paper presents the context of, and justification for, an Unconventional Natural Gas Development (UNGD) Health Registry. It does so by presenting the need for a comprehensive look at this growing public health problem; then provides a series of models and questions to help sharpen our focus on the challenges that a UNGD health registry would face and the solutions that could be employed.

Components of the paper

We first provide background information on shale gas development and its political context. Section 2 provides a discussion of emissions from UNGD processes. These emissions are broken down to water contaminants and air emissions. Special mention is made of radioactivity which is brought up from the shale after fracturing has occurred. Section 3 addresses the potential health consequences of exposures that residents are subject to because of their proximity to shale gas activity. This section reviews existing research on symptoms reported by individuals near UNGD activity. It also reviews, briefly, health consequences of some of the most consistently found UNGD emissions, namely, VOCs and particulate matter.

The second half of this paper is devoted to registries. Section 4 describes the benefits of registries generally and lays out different types of registries that can inform our thinking about a UNGD-related registry. We identify three relevant types of registries: exposure registry, disease registry and disaster registry. Section 5 introduces a set of questions that can serve as a guide to thinking about a UNGD health registry. The final section presents the outcome of a two-day workshop on a UNGD registry, which was attended by an invited group of experts and was held in June 2015.

I. OVERVIEW OF SHALE GAS DEVELOPMENT AND ITS CONSEQUENCES

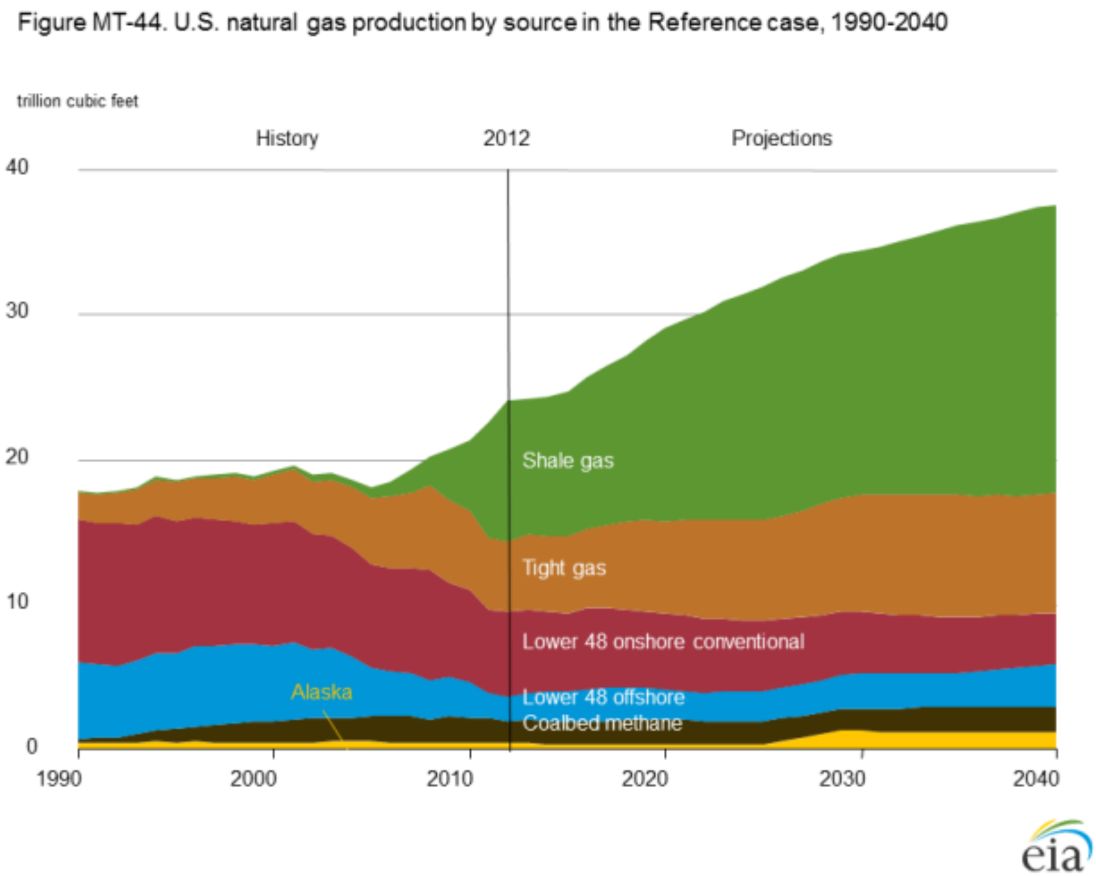
UNGD activities include drilling, extracting, processing, transport, and waste disposal. They occur in every region of the country.[*] By March 2013 31 states had significant or potential gas development.[1] As of February 2014 there were more than 1.1 million active oil and gas wells in

[*] In addition to hydraulic fracturing in shale for natural gas, gas is also extracted from tight sands and coal beds. Drilling in oil-bearing shale is also underway. This paper will focus on shale gas.

[*] Many policymakers believe that the development and use of shale oil and gas is a more environmentally

the US. Over 1.2 million Pennsylvanians live within a half mile of a well.[2] A 2011 EPA report estimated that 70 to 140 billion gallons of water are used to fracture 35,000 horizontal wells in the US each year.[3] Researchers have estimated that each fracking well in the Marcellus Shale formation could release 202 to 13,500 m^3 (53,300 to 3.56 million gallons) of contaminated fluids.[4]

Figure 1. Shale gas projections



http://www.eia.gov/forecasts/aeo/MT_naturalgas.cfm
From: The State of State Shale Gas Production. Richardson et al. June 2013.[5]

The reach of natural gas extraction and production goes beyond states where there are natural gas wells. Across the US, wherever there are natural gas pipelines there are compressor stations and metering stations that, like other UNGD activities, produce emissions. By 2006, according to the Energy Information Administration of the DOE, there were 1,200 compressor stations situated every 50 to 100 miles on both conventional and unconventional gas pipelines.[6]

As of 2012, there were 517 active natural gas processing plants in the lower 48 states.[7] The US has an estimated 827 trillion cubic feet of gas present in shale and tight sand formations in at least 26 states.[8] In November 2014, according to the US Energy Information Administration, there were 3,600 billion cubic feet of working gas (the volume of gas in excess of what is intended as a permanent inventory of storage to maintain adequate pressure and deliverability) in underground storage in the lower 48 states.[9]

Context

There is a growing body of emissions data that the natural gas industry has submitted to state regulatory agencies and that researchers have been collecting and modeling. The existing data are not comprehensive in terms of the content of emissions; and the accuracy of estimated emissions factors (rates at which facilities or operations emit) is difficult to determine. Nonetheless, these data sets are what researchers and community members have to work with to understand potential health impacts.

We know (or know estimates of) some of what is emitted at most points in the shale gas cycle – from creation of the well pad to separation, dehydration, and condensate tanks, to processing stations. We also know that drilling, hydraulic fracturing, compressing, and processing are occurring very close to places where people live and work and where children go to day care and school. Setback restrictions vary from state to state. As of 2013, twenty states had setback restrictions from buildings; they range from 100 feet in Ohio to 500 feet in North Dakota and Colorado. Only twelve states had setback restrictions from water sources.[10]

As shale development increases, so do reports of illness (see Table 1). Symptoms such as burning eyes, headaches, rashes, and cognitive changes are seen near UNGD sites across the country. Reports of such symptoms have been documented by researchers associated with universities, public agencies and non-profit organizations. These researchers are making progress in cataloguing the range of health conditions associated with UNGD and are investigating the mechanisms by which these effects may be produced.

Illnesses or conditions reported may be persistent, transient or intermittent. They may also be chronic, although it is difficult to estimate the incidence of those illnesses with long latency periods. With sporadic or consistent high intensities of exposure, four types of health effects can arise:

- Immediate acute effects, which appear in the nervous, respiratory, cardiologic, and dermatologic systems.
- Delayed effects, which occur after an accumulation of toxics in the body or after a toxic interacts with an existing health condition.
- Protracted effects, occurring from the body's inability to completely expel a toxic before another exposure intensifies it.
- Chronic effects from neurotoxics, carcinogens, and sensitization to chemicals. Chronic effects do not necessarily result from longer term exposures. For some substances, a single significant dose can precipitate the onset of disease.

Researchers have identified two key components of the health effects landscape: 1) specific emissions that could plausibly be associated with reported health effects; and 2) health symptoms reported by residents, which are relatively consistent across US shale plays. While results often converge on the same set of health conditions, among published and on-going UNGD health studies, many different methodologies, outcome measures, and subject pools have been used. This variability highlights the need for more systematic and standardized assessments of the current and potential health effects of living in close proximity to shale development activities.

Public health politics

Public health actions are, to greater or lesser degrees, political; and the establishment of a UNGD health registry is an especially political problem. Public health actions, like other public actions, reflect choices about principles, priorities and governance. By acknowledging the weight of the health risks that accompany shale development, the establishment of a registry contains an implicit political stance. It will reflect a balance sought between perceived economic and environmental[*] benefits and international influence on the one hand, and the government's interest in, and responsibility to, the public's health on the other.

The federal government's actions have, thus far, been defined by exemptions and legislative limitations; and disincentives to a federal public health response to UNGD have been created or exploited in that regulatory environment. In the absence of federal actions, however, states have had a history of policy innovation on environmental issues. Regulatory scholars, Rabe and Borick note that in recent decades,

> [i]t has become … increasingly common to anticipate state 'races-to-the-top' that emphasize environmental protection as a primary state policy goal, both to protect public health and to lure economic development sensitive to 'quality-of-life' indicators. Indeed, such races have often been triggered by so-called 'first movers' or early movers,' states that attempt to set the standard for others by early actions that are dramatic and innovative. [11]

Rabe and Borick contrast the state activity of recent decades with earlier patterns of environmental federalism in which "states would place a such a premium on short-term economic development opportunities that they would routinely downplay environmental concerns." They characterize such policymaking as an environmental "race to the bottom."[12]

The emergence of the shale gas industry is testing state commitments to environmental and public health protection in the face of economic and political gain; and thus far attention to public health has been overridden by commitments to energy development. Attention to UNGD produced health risks would be consistent with recent state "races-to-the-top" and is in keeping with their role as policy innovators. But protecting public health is, admittedly, a political decision fraught with competing interests.

[*] Many policymakers believe that the development and use of shale oil and gas is a more environmentally protective choice than other fossil fuels. This is, however, complicated and the overall body of research on the topic is not conclusive.

Brief summary of the extraction and production of natural gas

Excerpted from National Energy Technology Laboratory's *Modern Shale Gas Development in the United States: An Update*[13]
(A review of the UNGD equipment and terminology is found at the end of this paper)

Drilling Practices
Well pad construction begins. After construction of the well pad, a drilling rig will move in; a process that can involve 50-65 tractor trailers.
Shale wells are drilled both vertically and then directionally from the pad. Depending on the location within the play, the vertical portions of these wells are roughly 5,000 to 9,000 feet deep, most with horizontal laterals that extend for distances of from 3,000 to as much as 10,000 feet (Figure 34). When all the drilling is completed for the pad, the rig is moved off of the location prior to the hydraulic fracturing process beginning.
As the well is deepened, multiple strings of casing are run and cemented into place.
The well is turned if it is to become horizontal and the lateral portion of the well is drilled horizontally along the formation. Finally, production casing, typically 5 ½ inch diameter, is run to the bottom of the well and cemented into place.

Hydraulic Fracturing and Well Completion Practices
The large volume hydraulic fracturing treatments that are employed in Marcellus wells involve a lot of equipment operated in a closely coordinated manner. The equipment includes pump trucks, blending systems, storage tanks for water, sand and chemicals, tanks to capture produced liquids, piping systems to connect elements of the system, and specialized monitoring and control systems. The first step in the well completion process involves perforating the well casing in the horizontal portion of the well. A string of electrically activated shaped explosive charges are detonated in the casing across from the zone to be hydraulically fractured, perforating the casing and cement. The fracturing fluid is then injected under controlled high pressure to part the rock while the proppant (typically quartz sand grains) carried in the fluid "props" open the fracture when the fluid pressure is released and the fracture begins to close up. This propped fracture provides the permeability necessary for the gas to flow from the formation into the well.

Hydraulic fracturing shale gas formations like the Marcellus Shale typically involves the use of 3 to 6 million gallons of water per well. Convoys of tank trucks deliver this water, or in some cases it is pumped to the location through above ground plastic piping from large volume impoundments of fresh water constructed by the drilling company to service multiple well pads.

Fracturing generally along the horizontal lateral are sequentially perforated and fractured, beginning at the bottom ("toe") of the wellbore and working back toward the "heel" where the horizontal portion of the well begins. As many as 25 or more such treatments may be pumped within a single wellbore.

Following the hydraulic fracturing process the well is flowed back and tested using a controlled flaring process. In the Marcellus, roughly 20 to 25 percent of the water injected will come out of the well as "flow-back water." Over the life of the well additional volumes of the water will ultimately be produced, but as of yet it is unclear exactly how much will return to the surface. Both the flowback water and the produced water must be separated from the gas and hydrocarbon liquids, and either cleaned up and reused or disposed of in deep disposal wells. [Author note: flowback and produced water and their disposal is a problem that is not easily solved by the options mentioned in the previous sentence.]

Production Practices
After all of the wells on a pad have been drilled, completed (hydraulically fractured), and prepared for production (well heads, piping and surface equipment installed, flowback period completed) the wells are ready for production. The water and hydrocarbons (oil or condensate) produced along with the natural gas from multiple wells on a pad is separated and stored in tanks on the pad. In most situations within the Marcellus play the gas is sent through a gathering line to a central facility where it is processed before being compressed and piped to a

sales line. The condensate and water that is collected is trucked to a central tank battery where it is separated. Eventually, the water is sent for disposal in deep injection wells or cleaned and reused, the gas is delivered into a sales line, and the condensate is delivered to a pipeline or other transport alternative (tank truck, rail car, or barge) that can carry it to a refinery.

Midstream Processing and Transportation
Handling of the natural gas stream after production is done by what is termed the *midstream* sector of the natural gas exploration and production industry. In the Marcellus play the nature of the production stream —dry gas or wet gas— varies across the play. The southwestern Pennsylvania area produces a larger amount of natural gas liquids (NGLs) with the gas. Heavier liquids (condensate) can be removed at the well site or at centralized lease production facilities. But the gas must be pipelined to gas processing facilities (Figure 40) where the liquids content can be lowered much further, removing nearly all of the NGLs (ethane, propane, butane and iso-butane).

NGLs are separated from a gas stream by employing any of three different types of processing plants: "lean oil" plants, refrigeration plants and cryogenic plants. The first uses a petroleum solvent to absorb the NGLs from the gas stream. Refrigeration plants use propane to cool gas until most of the NGLs condense and can be separated, while cryogenic plants super cool the gas to remove nearly all NGLs.

After being processed to remove heavier hydrocarbons, the natural gas stream (now nearly all methane) is ready for transportation to the consumer [through natural gas pipelines]. The US enjoys an extensive system of natural gas pipelines and associated infrastructure (e.g., compressors to maintain the pressure needed to move the gas down the line), large portions of this infrastructure have been set up to move natural gas from the historical *producing* regions to historical *consuming* regions. [Author note: that infrastructure also includes metering stations which are situated between compressor stations along the pipeline.].

II. UNGD EMISSIONS

Federal obstacles to information

There remains uncertainty about the content and extent of air and water contamination, and in turn resident exposures, in part because the oil and gas industry has long been exempt from, or outside of, relevant regulatory structures. Exemptions, taken together, have the dual effect of making potential exposures more plentiful and making their disclosure less likely. The Safe Drinking Water Act (1974), for instance, regulates the injection of waste into drinking water sources. However, the National Energy Policy Act of 2005 (NEPA) exempted hydraulic fracturing from the underground injection provision except when the fluid injected contains diesel.[14] The Clean Water Act (CWA) regulates discharges of pollutants into waters and authorizes the EPA to establish quality standards for surface waters. The CWA exempts hydraulic fracturing from stormwater runoff provisions.[15] Water contamination is, at the federal level, also covered by the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) which established a federal fund to clean up abandoned hazardous waste sites and emergency spills, and includes mechanisms to locate those responsible and require their cooperation. Shale gas waste sites and spills are not considered hazardous under CERCLA.[16]

The unconventional oil and gas extraction industry is not required to report to the EPA's Toxics Release Inventory, a publicly available database containing information on toxic chemical releases and waste management. Furthermore, many of the chemicals used in hydrofracturing are considered proprietary or "trade secrets." This means that UNGD companies are protected from the mandate to report the full list of chemicals used on shale development sites. Some of these substances, therefore, do not appear on Material Safety Data Sheets (MSDS) typically available to workers on site and to first responders.[17]

Just as the UNGD industry is exempt from several federal regulation structures intended to protect water, it is also not well covered by regulations to protect air. This includes the provisions of NEPA and the Clean Air Act (CAA). The CAA regulates the release of pollutants into the air from stationary and mobile sources and authorizes the EPA to set national air quality standards. The oil and gas industry has largely not been covered by provisions of the CAA. Even as aspects of the Clean Air Act have been strengthened, consideration of much of the UNGD activities are considered as disaggregated minor sources thus beyond the scope of the CAA.[18]

Variation in releases

The absence of adequate regulation hinders the ability to quantify exposures. The variation in emissions themselves along the spectrum of shale gas development activities, also poses challenges. The contaminants released into air and water vary by process. They also vary by shale basin and even region within shale basin because the constituents of the shale layer can differ. When flowback water resurfaces it brings with it material from the shale layer itself. For instance, there may be higher levels of naturally occurring radioactive material (NORM) in the Marcellus shale (thus in the flowback water), than in other shale formations. Similarly, the proportion of methane to ethane in the shale environment differs among regions. Those with significant amounts of ethane produce “wet gas.” The ethane has to be separated out of wet gas and released, creating emissions that will not exist in low ethane shale regions.

Water contamination

Water exposures at the individual level occur when residents with water wells drink, bathe and cook with contaminated water. Concerns about water quality also include water ingested by pets and livestock from outside sources such as streams and ponds. Ingestion of, and skin contact with, contaminants are exposure pathways that have received attention, but inhalation of steam in a shower or when cooking will also increase exposure. Additionally, there are emerging concerns about soil contamination and subsequent use in gardening, agriculture and other outdoor activities. Children also come into contact with soil and plants as well as with water sources like streams and ponds.

Water contamination results primarily from three activities: 1) drilling and hydrofracturing; 2) leaks in impoundment ponds and other storage locations; and 3) water contamination which results from error, disregard for environmental regulations, and poor industry practices such as spills at the well pad and releases from wastewater trucks on the road and into streams and rivers.

Drilling and hydrofracking pose risks to groundwater and surface water both by the substances released from the geological formations and by the chemicals used in fracking operations.[19] Operations can contaminate surrounding drinking water sources from well known pathways including faulty well casing and abandoned mines nearby[20], [21], [22]). One to 3% of all unconventional gas wells have faulty seals.[23]

Inadequate pipe casing, cementing, or leaks through the well annulus are common in the petroleum/ natural gas industry.[24] An analysis of 75,500 compliance reports for over 40,000 conventional and unconventional oil and gas wells in Pennsylvania drilled from January 1, 2000 to December 31, 2012 shows a six-fold higher incidence of cement and/or casing problems in shale gas wells relative to conventional wells statewide. Unconventional wells spudded before 2009 in the northeast counties of the State are associated with the highest occurrence of loss of structural integrity (9.84%). However, unconventional wells spudded in the northeast region since 2009 (2,714 wells) show a similarly high rate of occurrence (9.18%).[25]

By one account 944 products containing 632 chemicals are used in the hydrofracturing process. Of the 353 identified by Chemical Abstract Service numbers, "[m]ore than 75% could affect the skin, eyes, and other sensory organs, and the respiratory and gastrointestinal systems. Approximately 40-50% could affect the brain/nervous system, immune and cardiovascular systems, and the kidneys; and 37% could affect the endocrine system; and 25% could case cancer and mutations."[26] Other researchers found that at least 750 different chemicals have been identified with hydrofracturing solutions (although a far smaller number are expected at any given site).[27] At least 29 of these chemicals are 1) known or possible carcinogens, 2) regulated under the Safe Drinking Water Act or 3) listed as hazardous air pollutants under the Clean Air Act.[28]

Substances commonly identified in fracking solutions include silica, acids (hydrochloric acid), viscosity adjusters (guar gum, borates, ammonium persulfate), corrosion inhibitors (isopropanol, acetaldehyde), iron precipitation control (citrate), biocides (glutaraldehyde), oxygen scavengers (ammonium bisulfite), scale inhibitors (acrylic polymers), and friction reducers (surfactants, polyacrylamide, ethylene glycol).[29] Others are methanol, diesel oil, naphthalene, benzene, xylene, toluene, and ethyl-benzene.[30] Many of the chemicals disclosed by the industry have identified health effects. However, for others, such effects are not known typically because the research has not yet been conducted.

Surface spills from fracking operations often contain significant amounts of organic contaminant chemicals. A recent study measured levels of BTEX chemicals (benzene, toluene, ethylbenzene, and xylene) from 77 surface spills at well pad operations in Weld County, Colorado. Groundwater samples collected within the spill evacuation area showed the National Drinking Water Maximum Contaminant Levels were exceeded for benzene in 90% of the samples, for toluene in 30%, for ethylbenzene in 12% and for xylene in 8% of the samples.[31]

Over 100 known or suspected endocrine disrupting chemicals have been reported in fracturing fluid. Researchers in Garfield County, Colorado found that water samples collected near sites where a spill or incident had occurred contained estrogenic, anti-estrogenic, androgenic, and anti-androgenic agents.[32] Benzene, xylenes, toluene, *tert*-butyl alcohol, isopropanol, glycol compounds, and other gasoline/diesel hydrocarbons were reported in domestic and livestock water wells located near fracking operations in Pavilion, WY.[33]

In addition to the chemicals pumped down the well, the water that returns to the surface, produced water, contains substances that exist in the geological formations. Among those substances are naturally occurring salts which can contaminate ground water once drawn back up the well.[34] Several studies have reported significantly elevated levels of bromide, chloride and total dissolved solids in well and surface water near fracking operations.[35] [36] [37] Radioactive material, too, can be brought back up with produced water. This will be addressed in a later section.

Air emissions

Water contaminants may primarily affect those with water wells that tap into potentially contaminated water tables and those near well pads and impoundment ponds where accidental spills can occur. Air emissions, on the other hand, have the potential to affect anyone in the vicinity of the emitting activity. Studies on the reach of air emissions are being conducted, and great uncertainty remains over what could be considered a safe distance from UNGD activity, particularly given the variability in emissions, topography and weather conditions.

Air emissions are most visible when a well is flared, that is, gases from the well are burned at the well head rather than entering the pipeline. But emissions are produced at every level of the UNGD process. They occur from vehicles and machinery used in constructing sites; the trucks used to bring millions of gallons of water to and from a well pad; and engines that power the drills and compressor stations. Condensate tanks, compressor stations, metering stations, and processing plants all have venting capacities which produce emissions reflecting their activity.

In addition to releases of gases and pressure through routine venting and flaring, operators release gases during maintenance, start-up, and shutdown of equipment to release pressure in the pipeline system, which can result in large volumes of emissions in a short time.[38]

Fugitive (uncontrolled or under-controlled) emissions can occur unpredictably. In a study conducted in the Fort Worth, TX area, researchers evaluated compressor station discharges from eight sites, focusing in part on fugitive releases. A total of 2,126 emission points were identified in the four month field study of eight compressor stations.[39]

Specific emissions are not found uniformly across all locations, indicating that emissions themselves vary among the stages of the extraction and production process (and, as stated earlier, the variation in the shale itself). In addition, there are many factors at play in capturing emissions through a sampling effort. These relate to timing, sampling protocols, weather, measurement instruments, and laboratory capabilities. Thus emissions recorded at the state level and in the literature vary, in part, because the methodology employed restricts researchers' ability to capture and document those emissions varies.[40]

The Pennsylvania Department of Environmental Protection (PA DEP) 2012 inventory of emissions from natural gas facilities includes CO, NOx, PM_{10} (particulate matter less than 10 microns), $PM_{2.5}$ (less than 2.5 microns), SOx, the VOCs, Benzene, Ethyl Benzene, Formaldehyde, n-Hexane, Toluene, Xylenes (isomers and mixture), 2,2,4-Trimethylpentane.[41] In Washington County that year the PA DEP collected data on over 300 individual sites (counting wells individually). The highest levels of emissions reported were of benzene, $PM_{2.5}$, NOx, formaldehyde, trimethyl pentene, and ethyl benzene.[42]

A study in the Dallas-Fort Worth metro area measured airborne VOCs at 39 outdoor residential sites located near natural gas facilities. About 100 volatile organic chemicals were detected in the air. VOCs collected at concentrations of at least 10 parts per billion (ppb) included c5 hydrocarbon, 2 methylbutane, c7 hydrocarbon, 3-methylhexane, c8 hydrocarbon, methacrolein, c12 hydrocarbon, c9 hydrocarbon, toluene, benzene, c6 hydrocarbon, m- and p- xylene, trimethylbenzene, dimethyl sulfide, carbon disulfide, c10 hydrocarbon, methyl ethyl disulfide, and C13 hydrocarbon.[43]

Some studies around UNGD activities have found benzene, particulate matter (PM), formaldehyde and other chemicals, at levels that exceed state or federal limits. The Texas Commission on Environmental Quality, for instance, reports in a 2010 memo on emissions that at one source, 35 chemicals were detected above "appropriate short-term comparison values". At some sites multiple chemicals (carbon disulfide, ethane, isopentane, and 1,2-dibromoethane) exceeded short-term health-based comparison values. Benzene was detected above the long-term health-based comparison value at 21 monitoring sites.[44]

Earthworks measured outdoor ambient levels of 19 VOCs near 34 Pennsylvania homes located within 5 miles of UNGD operations. VOCs detected within five miles of a site included acetone, methylene chloride, trichloroethylene, xylenes, toluene and benzene.[45]

The researchers associated with Earthworks, as well as others, have found air contaminants in rural areas and in combinations which one would not expect to find outside of industrial activity. Ninety-four percent of the samples tested for 2-butanone detected it; 88% of those testing for acetone and 79% of those testing for chloromethane detected them. Also frequently found were 1,1,2-trichloro-1,2,2-trifluorethane, carbon tetrachloride and trichlorofluoromethane.[46]

<u>Mixtures</u>

Mixtures of pollutants – whether in water or air – complicate the potential public health implications of UNGD. A large number of chemicals are released together from the various activities in natural gas extraction and processing. Health reference values (a dose or concentration under which there are not expected to be health risks) are not able to take the complex nature of the shale environment, its multiple emissions and interactions into full consideration.[47] Although the shale gas industry is not unique in emitting multiple pollutants simultaneously, the industry is notable for doing so in residential areas and near schools and day care centers.

Diesel is a mixture of chemicals and particulates that has received a great deal of attention. Diesel emissions are found consistently in the early stages of development – from construction of the drill pad through fracturing and removal of produced water. Gaseous hydrocarbons in diesel emissions include aldehydes, benzene, 1,3-butadiene, and polycyclic aromatic hydrocarbons (PAHs). In addition, emissions include fine and ultra-fine particles.[48] One to two thousand diesel trucks are used in a typical fracking operation[49], [50]; and these trucks disperse their emissions along miles of road as they travel to and from a site. This impacts a large stretch of land, passing by many residences and other buildings.[51] [52] [53]

Radioactivity

Naturally occurring radioactive material (NORM) is found in shale formations and can be brought to the surface in flowback and produced water and with the gas itself.

A 2008 publication of the International Association of Oil & Gas Producers explains,

> During the production process, NORM [Naturally Occurring Radioactive Material] flows with the oil, gas and water mixture and accumulates in scale, sludge and scrapings. It can also form a thin film on the interior surfaces of gas processing equipment and vessels. The level of NORM accumulation can vary substantially from one facility to another depending on geological formation, operational and other factors.

And

> Radionuclides … can … be found in pipelines scrapings as well as sludge accumulating in tank bottoms, gas/oil separators, dehydration vessels, liquid natural gas (LNG) storage tanks and in waste pits as well as in crude oil pipeline scrapings.[54]

NORM which has been concentrated through the extraction process and then is in contact with machinery and pipes is known as *technically enhanced* radioactive material, or TENORM. The EPA states that radioactive scale precipitates from produced water and can remain in piping, particularly that associated with separators, heater treaters and dehydrators. TENORM also contaminates UNGD equipment, including water handling equipment, gas processing equipment.

Exposure risks to waste disposal workers and residents or others working within 100 meters of a disposal site were acknowledged by the EPA. Furthermore, risks to the general population within 50 miles of a disposal site includes “exposures from the downwind transport of re-suspended particulates and radon, and exposures arising from ingestion of river water contaminated via the groundwater pathway and surface runoff. Downwind exposures include inhalation of re-suspended particulates, ingestion of food contaminated by deposition of re-suspended particulates, and inhalation of radon gas.”[55]

Specifically, researchers report evidence of radionuclides including those from the ^{226}Ra decay series (^{214}Pb, ^{214}Bi and ^{210}Pb) and the ^{232}Th decay series (^{228}Ra, ^{228}Th, ^{208}Tl).[56] Elevated levels of radionuclides (up to 50,000 Be/ Kg) were found in soil and sludge from reserve pits used in UNGD.[57] ^{226}Ra levels at a shale gas effluent discharge point in western PA ranged from 544 to 8,759 Bq/kg, which is approximately 200 times higher than the 22-44 Bq/kg levels found upstream and background sediments, and considerably higher than the US EPA limit of 185 Bq/Kg ^{226}Ra for drinking water and waste treatment sludge/solids.[58] In some circumstances wastewater from shale formations has been found to emit considerable levels of radon gas.[59]

Radon has a short half-life (3.8 days) but among its progeny are polonium and lead, and these are toxic with relatively long half-lives of 138 days and 22.6 years respectively.[60]

Worker Exposures

The oil and gas industry, overall, is known to create highly hazardous work environments, with OSHA attention more on safety than health hazards. With the exception of silica, there is little to no publically available research on the risks or health effects suffered by UNGD workers.[61] The EPA has documented the risk from silica inhalation and Esswein et al have characterized the risk as, in some cases, at least ten times the occupational health criteria.[62]

III. HEALTH CONSEQUENCES

We know that particulates, chemicals, and radiation can have health consequences, some from high short-term and perhaps repeated exposure and some from low-level chronic exposure. The pertinent literature on health consequences of exposures to shale gas industry activities falls into two categories. The first contains research, generally with small samples, at the community level, which correlates proximity to UNGD activity with illnesses and symptoms reported by individuals in the area.

The second, and far larger literature contains research on health consequences of exposure to particulate matter and chemicals, but not necessarily in the context of UNGD. We will restrict our comments only to particulate matter and several chemicals that are frequently detected or whose use in shale development is permitted by states.

Symptoms reported near UNGD sites

A wide range of health conditions have been documented around shale plays throughout the country; but a subset of those health conditions or symptoms are seen repeatedly (see Table 1). Researchers have consistently documented reports of, for instance, burning eyes, sore throats, stomach pain and nausea, headaches, and tingling or numbness in extremities.

Likewise, many people report increased anxiety and trouble sleeping and concentrating. It is uncertain whether the latter group is a consequence of physical exposure or whether these symptoms might result from the stress, worry and frustration many residents report in the face of nearby UNGD. Perhaps it is a combination.

Table 1. Research findings on health effects associated with UNGD

Category	Researcher/author
Behavioral/mood/stress	Earthworks (2012) Ferrar et al. (2013)[63] Perry (2013)[64] Resick (2013)[65] Subra (2009)[66]
Birth Outcomes	Hill (2012)[67] McKenzie (2014)[68] Stacy (2015)[69]
Cancer risk	McKenzie (2012)
Dermal	Earthworks (2012) Rabinowitz (2014)[70] Subra (2009)
Ear, nose, mouth, throat	Earthworks (2012) Subra (2010)[71] Subra (2009)
Eye	Bamberger & Oswald (2012)[72] Earthworks (2012) Subra (2010) Subra (2009)
Gastrointestinal	Bamberger & Oswald (2012) Earthworks (2012) Ferrar et al. (2013)
High Blood pressure	Subra (2010)
Muscle/joint pain	Earthworks (2012) Subra (2010) Subra (2009)
Neurological	Bamberger & Oswald (2012) Subra (2010) Subra (2009)
Respiratory	Bamberger & Oswald (2012) Earthworks (2012) Rabinowitz (2014) Subra (2009)

In addition to collecting data from individuals' self-reported health consequences, a few studies have used observations from existing large collections of health data based on location and proximity to gas pads. Three research teams have analyzed state birth outcomes data and information on proximity to, or density of, gas wells. McKenzie, using data on 124,842 births in rural Colorado between 1996 and 2009, reported that maternal residence within 10 miles of UNGD was associated with a significantly higher risk of several birth defects including congenital heart defects and neural tube defects.[73]

Hill examined birth outcomes among 22,257 singleton births born to mothers living with 2.5 km of well fracking operations and compared them with 1,116,978 overall singleton births over the period 2003-2010 in Pennsylvania. Mean birth weights were significantly lower among children born to mothers within 2.5 km of fracking operations. Maternal benzene exposure was linked to a 25% increased risk of low birth weight (<2,500 grams) and a 26% increased risk of Apgar score below 8.[74] Hill's low birth weight finding contrasts with McKenzie's positive correlation between birth weight and exposure to well sites.

Stacy et al investigated the association between proximity to UNGD and birth outcomes in southwest Pennsylvania. The researchers found no significant association with prematurity, but found lower birth weight and higher incidence of small for gestational age.[75]

Lastly, examining records of over 95,000 patients from the Pennsylvania Healthcare Cost Containment Council, researchers Jemielita et al, correlated inpatient discharge data with number of unconventional gas wells per zip code. The data suggest that UNGD wells were associated with increased inpatient prevalence rates within some medical categories, including cardiology and neurology. Cardiology inpatient prevalence rates were significantly associated with number of wells per zip code and wells per km^2 while neurology inpatient prevalence rates were significantly associated with wells per km^2. Furthermore, evidence also supported an association between well density and inpatient prevalence rates for dermatology, neurology, oncology, and urology.[76]

For articles that review the subject of health effects from UNGD see:

> Adgate, J.L., Goldstein, B. D., and McKenzie, L.M. "Potential Public Health Hazards, Exposures, and Health Effects from Unconventional Natural Gas Development". Environmental Science and Technology, Volume 48 (15): 8307-8320, 2014. http://pubs.acs.org/doi/abs/10.1021/es404621d
>
> Penning, T.M., Breysse, P.N., Gray, K., Howarth, M., Beizhan, Y. "Environmental Health Research Recommendations from the Inter-Environmental Health Sciences Core Center Working Group on Unconventional Natural Gas Drilling Operations". Environmental Health Perspectives, Volume 122 (11):1155-1159, 2014. http://ehp.niehs.nih.gov/1408207/
>
> Shonkoff, S.B., Hayes, J., Finkel, M.L. "Environmental Public Health Dimensions of Shale and Tight Gas Development". Environmental Health Perspectives, Volume 122 (8): 787-795 2014. http://ehp.niehs.nih.gov/1307866/
>
> Werner, A.K., Vink, S., Watt, K., Jagals, P. "Environmental Health Impacts of Unconventional Natural Gas Development: A review of the current strength of evidence". Science of the Total Environment, Volume 505 (2-15): 1127-1141, 2014.

Known health effects of chemicals and particulate matter

VOCs

While the frequency, concentration and duration of UNGD exposures are rarely known, thus the risk cannot be precisely determined, there is a great deal known about the potential effects of some commonly found agents. VOCs are a varied group of compounds with diverse health impacts, ranging from no known health effects to being highly toxic. Short-term exposure to some VOCs can cause short-term eye and respiratory tract irritation, allergic skin reaction, headaches, dizziness, visual disorders, fatigue, loss of coordination, and memory impairment. Long-term effects include damage to the liver, kidney, and central nervous system. Some VOCs, such as benzene, formaldehyde, and styrene, are known or suspected carcinogens.[77] The case for higher cancer risk for those living within a half-mile from well activity as compared to those living further away, has been made by McKenzie et al.[78]

The EPA reports the inhalation of benzene produces health risks including

> [acute (short-term)] drowsiness, dizziness, headaches, as well as eye, skin, and respiratory tract irritation, and, at high levels, unconsciousness. Chronic (long-term) inhalation exposure has caused various disorders in the blood, including aplastic anemia, in occupational settings. Reproductive effects have been reported for women exposed by inhalation to high levels, and adverse effects on the developing fetus have been observed in animal tests. Increased incidence of leukemia (cancer of the tissues that form white blood cells) have been observed in humans occupationally exposed to benzene. EPA has classified benzene as known human carcinogen for all routes of exposure.[79]

Benzene carries a risk of cancer[80], [81] and there is growing evidence that benzene is associated with childhood leukemia. Benzene affects the blood-forming system at low levels of occupational exposures. It has been argued in the literature that "[t]here is probably no safe level of exposure to benzene, and all exposures constitute some risk in a linear, if not supralinear, and additive fashion."[82]

Also detected near UNGD sites is methylene chloride, a compound often used in solvents.[†] According to the EPA

> The acute (short-term) effects of methylene chloride inhalation in humans consist mainly of nervous system effects including decreased visual, auditory, and motor functions, but these effects are reversible once exposure ceases. The effects of chronic (long-term) exposure to methylene chloride suggest that the central nervous system (CNS) is a potential target in humans and animals. Human data are inconclusive regarding methylene chloride and cancer. Animal studies have shown increases in liver and lung cancer and benign mammary gland tumors following the inhalation of methylene chloride.[83]

Formaldehyde is considered a Hazardous Air Pollutant (HAP) by the EPA and is found near UNGD sites.[84] It is one of the emissions that the natural gas industry is required to report to some state agencies. Air exposures to formaldehyde target the lungs and mucous membranes and in the short-term can cause asthma-like symptoms, coughing, wheezing, and shortness of

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[†] Methylene chloride is not widely cited in the academic literature on UNGD emissions, however, it, and other halogenated alkanes, have been documented by researchers in the field and the authors of this paper believe it is an important compound to consider.

breath. Ingesting high doses of formaldehyde can cause convulsions, mouth and stomach pain, nausea, vomiting, vertigo, and diarrhea. The EPA classifies it as a probable human carcinogen.[85] The National Toxicology Program of the Department of Health and Human Services as well as the World Health Organization classify it as carcinogenic to humans.[86]

Particulate matter

Numerous epidemiological studies have demonstrated a consistent link between particulate matter and increased cardiopulmonary morbidity and mortality.[87], [88], [89] Inhalation of $PM_{2.5}$ can cause decreased lung function, aggravate asthma symptoms, cause nonfatal heart attacks and high blood pressure.[90] $PM_{2.5}$, it has been suggested, "appears to be a risk factor for cardiovascular disease via mechanisms that likely include pulmonary and systemic inflammation, accelerated atherosclerosis and altered cardiac autonomic function. Uptake of particles or particle constituents in the blood can affect the autonomic control of the heart and circulatory system."[91]

Research on impacts on pregnancy and birth outcomes suggests that in pregnant women, the high particulate pollution found near highways (which has many commonalities with shale gas pollution) "may provoke oxidative stress and inflammation, cause endocrine disruption, and impair oxygen transport across the placenta, all of which can potentially lead to or may be implicated in some low birth weight … and preterm births." These are immediate consequences in infancy, but further on "low birth weight and preterm birth can affect health throughout childhood and in adulthood."[92]

Diesel. Diesel is prevalent from drill pad development through finishing stages. High levels of diesel exhaust from construction machinery and trucks increase the level of respirable particles. Health consequences of diesel exposure have been widely studied and include immediate and long-term health effects. Diesel emissions can irritate the eyes, nose, throat and lungs, and can cause coughs, headaches, lightheadedness and nausea. Short-term exposure to diesel exhaust also causes inflammation in the lungs, which may aggravate chronic respiratory symptoms and increase the frequency or intensity of asthma attacks. Long-term exposure can cause increased risk of lung cancer.[93]

Limits of existing research

UNGD is a relatively new area of public health inquiry and much of the initial focus was on water contamination from the fracking stage of well development. The problem, however, is far broader and more complex so a great deal must be investigated to better understand the public health consequences of UNGD. The existing research on potential health effects from exposure to UNGD activities suggests that there is an association between exposures and symptoms. Causal linkages between specific agents and specific physiological responses, however, have been difficult to establish given the limited access researchers have to a full accounting of emissions at a particular site. Furthermore, the mixtures of agents released may have health consequences that have never been precisely identified.

An examination of the existing studies reveals that variables were defined and data were collected in different ways. Most of the studies involved only a small number of cases and relied on convenience samples (without random selection or controls). Some studies relied on health data already collected (as in the case of the birth outcomes research) others relied on self-reports by the subjects. It is worth noting that a complication is posed by the necessity of relying on state datasets for background health levels, which are often only available two or more years after data are collected and vary state to state. Taken together, the research does not yet allow us to specify with certainty the scope of the public health problem.

IV. WHY A REGISTRY?

The inconsistent manner in which early research on the health consequences of UNGD has been conducted; the inconsistent documentation of illness plausibly linked to UNGD; and gaps in knowledge about the full range of exposures, lead us to the proposal of a standardized registry. That is because, notwithstanding those inconsistencies, we believe there are health effects produced by UNGD activities. It is important to find mechanisms to respond to individuals who are being exposed to contaminants at their homes, schools and workplaces. A registry is one mechanism that deserves attention.

Registries can be categorized along several different dimensions. A useful distinction for the purpose of developing a UNGD registry is that some registries are used for well-understood diseases and have among their goals to monitor the incidence and prevalence of the disease and detect patterns among cases. Others can serve as a surveillance system for the occurrence of unexpected or harmful events resulting from products or services (often medical). Still others – which will be our focus in this paper – are intended to shed light on an incompletely understood disease or constellation of health conditions that appear to have the same origin or etiology. Such registries can play an instrumental role in defining associations between environmental exposures and adverse health events.

In its most basic form, a registry is a dataset of uniform information about individuals collected in a systematic and comprehensive way, in order to serve a predetermined medical or public health purpose. The National Committee on Vital and Health Statistics describes a registry as

> an organized system for the collection, storage, retrieval, analysis, and dissemination of information on individual persons who have either a particular disease, a condition (e.g., a risk factor) that predisposes [them] to the occurrence of a health-related event, or prior exposure to substances (or circumstances) known or suspected to cause adverse health effects.[94]

Benefits to patients who join a registry include receiving notification of research studies, learning about advances in the knowledge of their disease, and connecting with experts in the disease. In addition to providing important information to patients, registry data has benefits for research and policy decision-making.[95] Over time, resulting changes in policy and regulation can have tangible, positive outcomes for protecting air and water quality and health (e.g., air emission controls or contained waste storage).

In this section we present:

- Types of registries
- Basic structures of registries
    - Health criteria
    - Exposure criteria
- Existing registry models
- Elements of a UNGD-related registry
    - Criteria for exposure
    - Criteria for illness
    - Recruitment
    - Problems of information-sharing

Types of registries

Disease registries. All registries have criteria and standardized mechanisms of inclusion which determine the basis upon which a registry solicits particular individuals' information. Disease- or condition-based registries use the state of a particular disease or condition as the inclusion criterion. In disease or condition registries, the patient may have a chronic disease, such as cystic fibrosis or diabetes. Or criteria may include an illness of a more limited period of time as in the case of infectious diseases. Registries dedicated to a particular illness often enroll patients at their health care setting, although patients may also be enrolled through voluntary self-identification processes that do not depend on utilization of health care services.[96]

For research purposes, a disease registry is like a case control study, where a well-defined outcome has already occurred and the purpose of the registry is to determine what the risk factors are that contributed to that outcome. For public health purposes, a disease registry might be used to consider what interventions could be used to reduce the risks of the disease or to determine if individuals with the disease have had appropriate diagnostic testing or post diagnosis care. Individuals with the disease may not necessarily know that they are part of a registry. Disease registries in which individuals are aware of their participation may provide updates to enrollees such as results of ongoing research or information about treatment options.

Exposure registries. The inclusion criteria of environmental exposure registries is based on whether an individual was exposed either to a specific substance (like asbestos) or an uncertain set of exposures as in the case of the Gulf War. Exposure registries are similar to a cohort study, and can be prospective or retrospective, but participation is based on a common exposure. The intent of the registry is to understand the health implications of the exposure. Typically this would require an adequate determination of exposure, an appropriate reference group and years of follow-up. Most exposure registries involve a single exposure.

Disaster registries. A form of registry that may have particular -- though perhaps unexpected -- relevance to UNGD is a registry that is created after a disaster. A disaster registry is a form of exposure registry, but based on an event and may involve more than one exposure or even unknown exposures. There is no set methodology for registries that fall under this category. They arise from the immediate need that public health care providers, policy makers, and other stakeholders have for insight into health status and needs of an affected population after a disaster. Since a disaster might have direct consequences for public health care, a clear overview of health needs is important. Rapid assessment methods are used to collect reliable, objective information that is immediately required for decision making in the recovery phase of the event. With collected information about health status and needs, public health interventions and policy responses can be prioritized.

Morgan and Odams explain that environmental disaster based registries can be particularly useful in the following five situations, which seem applicable to UNGD circumstances as well.[97]

- Outcomes are anticipated but the extent or timing may be uncertain.
- There is a long period between exposure and health outcome.
- Health and/or social care needs to be provided to the affected populations.
- Public reassurance about the absence of disease is needed, when appropriate.
- Exposures and health outcomes are uncertain.

Registry models – defining exposures, participant populations and outcomes

To consider the possible elements of a UNGD health registry it is useful to look at the purpose and structure of several existing registries. For guidance we present five examples of registries reflecting environmental exposure or disaster models.

- World Trade Center Registry – including in its population anyone in a portion of lower Manhattan on 9/11.
- Benzene Registry – part of the National Exposure Registry – looking at long term health consequences to the general population from a long term low level exposure.
- Operation Tomodachi, Japan Registry – US Department of Defense workers who could have been exposed to radiation following the 2011 earthquake and tsunami.
- Gulf War Registries – including military personnel who were in areas that could have resulted in health effects.
- New York Heavy Metals Registry—based on blood tests required to be submitted by health care providers to the State.

<u>World Trade Center Registry</u>

The World Trade Center (WTC) Registry includes over 71,000 subjects (including nearly 3,000 minors) exposed to the 9/11 WTC disaster.[98], [99]. Residents, workers, police, fire, and cleanup crew members were all exposed to a wide range of chemicals including combustion products, asbestos, wood, paper, cement, metals, jet fuel, and diesel exhaust. The WTC Registry included people present in the WTC buildings on 9/11, workers who worked at least one shift of rescue or cleanup work, persons who lived and worked in Manhattan south of Chambers and Canal Streets, and schoolchildren and staff who were in school near the WTC.[100]

The WTC registry was funded by a $20 million grant from the Agency for Toxic Substances and Disease Registry (ATDSR). In addition to subject interviews, objective data such as lab tests, radiology, pathology, and pulmonary function tests were made available to the registry. Objective exposure data are lacking for the first several days following 9/11, which may have been a critical period. There is also some concern about how representative the registry group was relative to the entire WTC exposed population.[101]

The WTC registry has been useful in detecting long-term health problems of both residents and workers at the WTC. Analysis of the WTC Registry data has shown that exposures in the general public have been linked to significantly higher risks of heart disease in women[102]; lower respiratory illness (cough, wheezing, shortness of breath)[103]; post traumatic stress disorder[104] ; skin rashes[105] ; prostate cancer, thyroid cancer and multiple myeloma[106]; and higher risk of pre-term birth and low birth weight babies[107].

Registry data analysis has indicated that exposed WTC rescue or cleanup workers have been linked, additionally, to significantly higher risks of sarcoidosis[108] and higher overall cancer rates and rates of thyroid, prostate, and lymphoid/ hemopoeietic, and soft tissue cancers[109].

Gulf War Registry

The Gulf War Registry has been useful for studying the health conditions of Gulf War (GW) veterans and for formulating theories and possible mechanisms related to Gulf War Syndrome (GWS). By 1997, well over 74,000 GW veterans volunteered to be examined, receive appropriate medical tests, and be entered in the Gulf War Health Registry.[110] This registry is used to recognize and pursue symptom patterns commonly found in GWS veterans. Common symptom patterns include: 1) fatigue/ mood and mental health problems; 2) musculoskeletal problems; 3) gastrointestinal problems; and 4) respiratory and throat problems.[111]

Other data analyses show that 1) lung cancer risk is significantly elevated in GW veterans as compared to controls, while overall incidence of cancer is similar in both groups[112]; 2) incidence of amyotrophic lateral sclerosis (ALS) before age 45 years was significantly elevated in GW veterans[113]; 3) 16% of registry participants meet criteria for chronic fatigue syndrome (CFS); and 13% meet criteria for multiple chemical sensitivity (MCS)[114]

Operation Tomodachi Registry

The March 2011 earthquake and tsunami in Japan severely damaged the Fukushima Daiichi Nuclear Power Station, which resulted in the release of radiation into the environment. The Operation Tomodachi Registry, operated by the U.S. government, is intended to estimate the radiation doses experienced by Department of Defense-affiliated individuals who were on or near the mainland of Japan between March 12 and May 11, 2011. Individuals present at any of the 13 shore-based locations or on the US Navy ships and aircrew in the area during this period were eligible for inclusion in the registry.

The Operation Tomodachi Registry characterizes who was exposed to radiation and where those individuals were at the time of exposure, using individual radiation data, ambient radiation exposure data and medical record data. The registry was intended to be used for medical treatment and diagnosis; epidemiological health outcomes studies; medical surveillance and claims adjudication; and responses to DOD employees.[115]

There is publicly available research on pregnant women in the Operation Tomodachi Registry and their birth outcomes. There were 590 potentially exposed pregnant women on or near mainland Japan at the time of the accident. Nearly 97% resulted in live births and 3.5% were lost. Of the live born infants, rates of birth defects, in utero growth problems, and pre-term birth were similar to those in the Department of Defense's registry of birth outcomes for the military as a whole.[116]

Benzene Subregistry of the National Exposure Registry

Operated by the ATSDR, the National Exposure Registry assesses the long-term health consequences from long-term, low-level exposures to specific substances in the environment. The Benzene Subregistry, begun in 1991, includes individuals in south central Texas who had environmental exposure to benzene in tap water. Face-to-face interviews were used to collect self-reported information. Follow-up questioning occurred one and two years after the initial interview. The Benzene Registry has had intense oversight and high levels of follow up.

The Benzene Subregistry has identified adverse health outcomes that were also documented in the National Health Interview Survey (NHIS) population. In at least one time period researchers found (in certain age and sex groups) increases in anemia and other blood disorders, ulcers, gall bladder, stomach or intestinal conditions, stroke, urinary tract disorders, skin rashes, diabetes, kidney disease, and respiratory allergies. Overall, an array of respiratory, joint, hearing, and speech deficits were significantly higher in those exposed to benzene.[117]

New York State Department of Health – Heavy Metals Registry

At high enough concentrations, heavy metals can be toxic when ingested or inhaled. If exposure is repeated or continuous, metals can bio-accumulate becoming more dangerous over time. The Heavy Metals Registry (HMR), established in 1980, of New York is a surveillance tool for adult exposures to lead, mercury, cadmium, and arsenic funded by the State of New York. The New York Department of Health (NYSDOH) receives reports of all blood lead tests performed on NY residents, along with reportable levels of mercury, arsenic, and cadmium. All clinical labs, physicians, and health facilities must provide the NYSDOH with blood test results of its patients if the metal is above a certain level.[118]

HMR personnel review and evaluate registry data in order to implement prevention efforts. In its 2006-2010 Report, NYSDOH documents an increase in arsenic exposure (possibly due to increased public awareness and fish consumption). The Report notes that there has been a steady decline in blood lead levels since the mid-1990, with Hispanics having the highest rate of exposure. Mercury exposure began to increase sharply in 2000, then dropped in 2010. Nearly all of those reported to the HMR with identifiable exposures during 2001-2008 had non-occupational exposures resulting from seafood consumption.[119]

V. ELEMENTS OF A REGISTRY OF UNGD EXPOSURES AND / OR RELATED ILLNESSES

Having reviewed the emissions and health concerns surrounding UNGD and explored registries that focus on environmental exposures, we now turn to questions that can guide the consideration of developing a UNGD health registry. A UNGD registry would have to contend with a unique set of challenges. First, there are limitations in emissions and exposure data. Second, health complaints and symptoms are varied, and many are commonly reported where there is no shale gas activity. Third, industry reporting and disclosure of practices are limited, making it difficult to draw connections with health impacts experienced by residents. Lastly, there are scientific, social and political forces questioning or contesting the existence or extent of UNGD-related illnesses. These forces impact the funding of research on emissions, exposures and health consequences. Furthermore, they drive public messaging and public education. As a result, there is inconsistent recognition among stakeholders, health professionals, policymakers, and the citizenry at large, that UNGD emissions pose public health risks. These are significant, but not insurmountable, challenges.

Options for exposure and illness

Exposures from UNGD take many forms. They are produced by trucks and construction equipment when building the site; and by an array of equipment and infrastructure, including that associated with the drilling, hydrofracturing, and flaring of the well. Further down the line emissions are produced by pipelines, compressor and metering stations, processing plants, and underground gas storage sites. An individual residence may be subject to emissions from several installations. It is not uncommon for a home to be within 2 miles of multiple well pads, compressor stations and a pipeline.

Questions raised by this exposure configuration are:

1. Would the registry include exposures from the full range of UNGD activities and facilities or just a portion? Would the unusually high concentration of truck traffic be included?
2. Could a single specified emissions component serve as the exposure that would determine inclusion into the registry database? Could, for instance, BTEX or $PM^{2.5}$ be the surrogate exposure for a wide range of others?
3. Alternatively, should inclusion into the registry database be site-defined rather than emission-defined? Could close proximity (e.g., within one mile) to, for instance, a well pad, processing plant, or metering station be the exposure that merits inclusion into a registry?

Questions about exposure documentation:

1. Is exposure verification or documentation necessary for inclusion into the registry database or would self-reported data be sufficient? If documentation would be required, what level of data would suffice?
    a. Would standard air/water testing protocols and results within a specified range be required?
    b. Would data from state emissions inventories for natural gas activity be sufficient to imply exposure? Are state datasets accurate and reliable?
2. Would the duration of a resident's exposure be considered for inclusion? How would that be documented?
3. If exposure documentation is not required for inclusion into the registry database, what kind of information would be needed?
    a. Would proximity to one (or more) phases of the extraction process for a specified period of time make a resident eligible?
    b. What is the appropriate distance for such proximity?

Questions about health characteristics of participants in registry database:

1. Must there be an existing health problem plausibly related to UNGD? Could it be a past problem? Could it be a mental health problem? What if an individual's pre-existing health condition is plausibly exacerbated by UNGD? For example, is the model of work related asthma assessments in which both occupationally caused and exacerbated are used/accepted, appropriate here?
2. If health symptoms serve as criteria for eligibility into the registry, what level of documentation would be required?
    a. How would health effects be defined, validated, recorded?
    b. Are self-reported symptoms sufficient for inclusion or is a health care provider assessment required?
    c. Could documentation of a single symptom plausibly related to UNGD be sufficient for inclusion or should there be more than one?
    d. How should common, non-specific health complaints such as sore throat, fatigue or headache be considered?

A word about psychological effects

Several studies have pointed to the psychological effects of living near UNGD. Researchers have documented reports of stress, worry, situational anxiety, and depression (which themselves can cause physical symptoms and illness). A study by Resick (2013) documents the loss of control and hopelessness that accompanies shale activity. An insight developed by Resick et al and also by Greiner (forthcoming) is that to understand the effects of living near UNGD activity, one must consider the full breadth of the construct of health which includes a sense of well-being. Both the Gulf War and the 9/11 registries took mental health into consideration when documenting health effects.

3. Should there be additional qualifications? Should there be more than one criteria?
    a. Must a person document both a health effect *and* an exposure?
    b. Could the registry be restricted to a sub-population, perhaps in its initial phase? For instance, only students (for whom there is already some publicly collected data? Or only birth outcomes and infants?)
4. Could the registry be based on a particular health condition? Should it focus, for example, only on respiratory illness?
5. Should oil and gas workers be included, even sought out for inclusion in the registry? If so, are there conditions defining their inclusion such as the length of time in the industry?

Recruitment and inclusion

Accepted definition of illness. Registries can reach out directly to individuals who might be appropriate participants or they might reach out through existing channels such as health care providers or advocacy groups. Anecdotally, it seems that there are few doctors, clinics, or hospitals that would identify people as having illnesses caused by UNGD. There are two related reasons for this. As of yet, there is not a widely accepted case description of what it means to suffer health effects from UNGD exposures, although the Southwest Pennsylvania Environmental Health Project has developed and begun to circulate one (see Appendix A).

Problems of information-sharing. The UNGD-affected population may pose unusual challenges to those who try to recruit them. Those in close proximity to shale gas activities may, in fact, be reluctant to share information and resist being associated with a program that implicates the industry in doing harm. Individuals may, in fact, have a vested interest in the industry and/or its effect on the local economy.

What makes the population near UNGD activity unique is the prevalence of non-disclosure agreements (NDAs) signed by those residents who are likely to be heavily exposed to UNGD emissions. NDAs are legal agreements that, in this case, a resident might make with a gas company (or sub-contractor). In these agreements a resident often takes monetary compensation from a company doing work on the resident's property in exchange for his or her legal agreement not to discuss their experience or provide any health or exposure information with anyone. Once an NDA has been signed, that resident has foreclosed his or her opportunity to share health information. This must be considered with respect to enrolling participants and getting data on the full spectrum of those affected by UNDG.

An online Bloomberg News article explains

> In cases from Wyoming to Arkansas, Pennsylvania to Texas, drillers have agreed to cash settlements or property buyouts with people who say hydraulic fracturing … ruined their water…. In most cases homeowners must agree to keep quiet. The strategy keeps data from regulators, policymakers, the news media and health researchers, and makes it difficult to challenge the industry's claim that fracking has never tainted anyone's water.[120]

VI. MEETING OF EXPERTS TO CONSIDER A UNGD HEALTH REGISTRY

This white paper, on considering a UNGD health registry, is intended to help determine (1) whether enough is known about emissions and exposures produced by the shale gas industry; and (2) whether health risks are present. If the answers to those questions are *yes*, then the next question is whether a registry of health effects would be a useful public health tool for understanding and addressing the health effects resulting from living, working or going to school in close proximity to UNGD activity. Registries often, though not always, fall under the domain of government entities. Whether a UNGD registry should, or would, be initiated or funded by a federal or state agency is an open question. If not a government agency, could a non-governmental agency build and administer a registry? And what form should a registry take? In the face of this politicized and complex public health problem, all possibilities are well worth considering.

Registry Workshop Discussion and Outcomes

On May 4 and 5, 2015, 25 experts in the effects of shale gas development, environmental health, public health, and registries met in Chicago to address the need for a registry of those exposed to and/or made ill from shale gas (and oil) development. The white paper, *The Case for an Unconventional Natural Gas Development Health Registry*, provided a common language and a scaffolding of empirical information on the UNGD process, emissions and potential health effects. The workshop participants articulated the value of a registry and over the two days, converged around two pathways toward the long-term goal of a comprehensive UNGD health registry. The discussion roughly tracked the series of questions presented in the white paper, with an emphasis on (1) the goals of a UNGD registry; and (2) the best starting point for achieving the identified goals.

By the close of the meeting we had gained clarity on potential ways to move forward. The discussion focused on achievable short-term and long-term steps that could be taken by those around the table, non-profit organizations, community groups, universities, and government agencies.

Goals of a UNGD registry include:

- Case identification
- Standardized data collection
- Opportunities for researchers to investigate health effects
- Communication with residents to convey risk, validation, and health protective steps
- Raising awareness of physicians and public health professionals
- Influencing regulatory policy
- Providing a repository of tools for research

Starting points

Based on the evidence of exposures and health effects and the needs of the communities, the group considered potential starting points. Ideas included a registry of a sub-group of those potentially affected (birth outcomes, school children), a more simple roster, a case-control study, and research using existing datasets.

By the close of the workshop, three complementary recommendations had emerged:

1. Develop a statewide, regional, or national roster as a step towards a more in-depth registry.
2. Tap into, and cultivate relationships with, residents and grassroots groups to formulate a community-responsive roster.
3. Take stock of existing data collecting agencies and datasets with an eye toward their potential to illuminate exposures, health effects, and their relationships. Capitalize on existing channels for tracking relevant health and environmental information.

Any actions taken, participants argued, must respond to the needs of individuals at risk. They emphasized the importance of getting information out to residents and, broadly, to communities affected by UNGD. In addition, all steps require thinking through the roles that various players could play: academic or other researchers, state and federal government, NGOs, and community or grassroots groups that come together because of individuals' concerns about UNGD.

The discussions focused on variations of rosters and registries and were an exploration of possibilities rather than the creation of a single model. For this reason, the group did not consider the cost of creating and maintaining a specific roster or registry. Moving forward, however, sources of funding and budget constraints will be a priority.

1. Rostering Effort

In considering a registry, important, complex questions emerge about definition and measurement of exposure as well as definition and documentation of health effects. In addition, funding and administration of a large-scale registry takes significant time to work out. In the meantime, proceeding with a roster rather than a fully developed registry, allows progress to be made. Moving at a quick and determined pace is important because exposures are on-going; the public health problem is urgent; and, as one participant pointed out, we are losing people who might have signed up for a registry a couple of years ago, but have since moved away or simply given up.

Scope/Objective. A roster, whether local, regional, or national, has the potential to generate a meaningful dataset. A roster structure is useful in cases where both the exposures and the health effects are uncertain. It can help generate hypotheses and represents an important step toward revealing the associations between exposure and health effects. A roster can serve as a mechanism for bringing exposure and health information to individuals living in proximity to shale gas development.

Designing a Roster: A web- and phone-based roster for shale gas development impacts could revolve around a simple set of questions. Its aim would be developing a database of individuals who consider themselves at risk from UNGD exposures. In its limited form, it could simply ask:

"Do you feel you've been impacted by shale gas development? If so, can you provide two ways we can contact you in the future?"

There was discussion about whether proximity mattered at all at this stage. Because rostering is the first step and not a fully formed registry, it was suggested that the organizers cast a very broad net and not be concerned with the extent of the exposures nor the presence of illness. Those could be sorted out later. As one participant put it, "The most important thing about a registry is getting people into the registry!"

Participants in the meeting often circled back to the need for standardizing the intake of information, however simple. If governmental and non-governmental agencies used the same intake protocol, the data could be aggregated across efforts creating a powerful dataset. Later questions may be more detailed and we would benefit if they were standardized as well. It was also suggested that subsequent questions could be tied to reference group data such as those of the National Health and Nutrition Examination Survey (NHANES), the Behavioral Risk Factor Surveillance System (BRFS) and the SF36, which is the RAND 36-item functional health and well-being survey instrument.

Questions/concerns: The issue of potential boundaries for a roster or registry was raised. The long term plan could be for a series of state registries, regional registries reflecting differing shale formations, or one overarching national registry which could draw from satellite registries across the country.

There were questions about data sharing – between state-level departments and academic researchers and about consent and institutional review board (IRB) approval. Participants were additionally concerned about potential for a breach of security in the data system and also about the possibility of legal action in which registry administrators are subpoenaed for their access to registry data.

Implementation challenges: A two-pronged question the group discussed was where a roster's data would be housed and who would take responsibility for it. Who would be the keeper of the data? This gets complicated quickly. Participants considered, but did not reach consensus on, whether it would it be best under the control of a state health department, an academic institution, or perhaps a joint state-university program. Could FracTracker or another non-profit organization play a role? Could a consortium have authority and responsibility for the database?

The National Institute of Environmental Health Sciences' Gulf Long-Term Follow-Up Study was brought up as an example of large scale health data collection. Data was collected by NIEHS for a longitudinal study of individuals who helped with the Gulf BP oil spill cleanup, took training, signed up to work or were sent to the Gulf to help in some way. The study grew out of a voluntary roster of response workers developed by NIOSH. The roster's objectives were

> (1) to create a record of those who participated in the Deepwater Horizon Response activities, (2) to collect information on the nature of their projected work assignments and the training they received, and (3) to create a mechanism for contacting them about

possible work-related symptoms of illness or injury during and after the response, needed.[121]

The rostering effort resulted in a data set of more than 55,000 workers. By 2013, 33,000 participants had joined the study, which examines how oil spill clean up may have affected workers' current and future health. It is also examining the effects of stress and job loss on both physical and mental health.[122] Some at the workshop noted that NIEHS had developed best practices that are relevant to the establishment of an UNGD registry or roster.

Rostering Recommendation: Establish A Pilot State Roster (Colorado)

The Colorado Department of Health has already received funding to establish a health response hotline. It plans to develop a set of intake questions and a follow-up protocol. Participants at the meeting discussed providing Colorado with input from NGOs, academic institutions, and other interested health departments in designing instruments and identifying a standard set of questions – if that input is wanted. A standardized approach to the roster would then allow Colorado's initiative to serve as a replicable model.

Rostering Recommendation (2nd Step): Establish A National Roster

Like a statewide roster, a national (or even regional) roster would serve as 1) a data collection process; 2) a communication tool for providing information to concerned communities and 3) a contact list that researchers could potentially draw upon to gather needed data. The work group tasked with exploring the roster thought that a national roster could constitute the beginning of a significant health impact assessment effort.

Participants did not see a rostering or registry effort being picked up by a federal agency, although some participants hoped it would. A roster with national coverage would likely need to be developed and managed by an NGO or consortium of NGOs, according to some of the registry workshop participants. One benefit of a national effort is that it would be accessible to those in states who are not doing any rostering of their own. Without federal action, a comprehensive roster would depend on individuals, community groups and larger organizations to recruit and enroll members. Some participants at the workshop argued for a roster design that would be based on, or at least capitalize on, grassroots efforts and would involve community members' input at different stages of the process.

2. Existing Data Sources

There was interest at the meeting in pursuing existing data and existing channels of data gathering which might be used for addressing the need for a UNGD registry. Several participants thought it was critical to take a good look at the current landscape of relevant information already being collected. There was discussion of the wide variety of data gathering efforts – larger and smaller, related to health and related to exposures – that should be examined.

Health data. Health datasets include school data, health department records, vital statistics, and registries such as those for cancers and birth defects. Public sources of health data (although not necessarily publically accessible) include Medicaid and Medicare data; occupational data from OSHA and NIOSH; even Poison Control. CDC and ATSDR conduct pertinent and valuable surveillance efforts. The question was raised whether UNGD health effects could be summarized into a reportable condition that could then be picked up by state health departments or CDC. Hospital and medical group databases will have diagnoses, treatments, emergency, and billing information that can potentially be useful. As mentioned earlier, one group of researchers examined hospital patient discharge records numbering over 95,000. They then determined associations between prevalence of certain medical conditions and density and number of wells in each patients' zip code.[123]

None of these health data sources makes an explicit connection to UNGD so researchers would need to find surrogates for exposures and look for unusual health care patterns if these are to be fruitful sources for them. Additional limitations of examining data from health care systems include the fact that symptoms that occur from UNGD do not necessarily prompt people to seek medical help. Furthermore, health effects seen thus far are often general (i.e., not discernably different from symptoms produced by other causes). Frequently reported are headaches, nausea and fatigue.

Exposure data. States, localities, NGOs and academic researchers have collected some emissions data, mostly near well pads but also near other parts of the UNGD infrastructure and in residents' homes. There is also data on precise locations of, and emissions from, well activity. There is modeled data, production data, violation/accident records, building and emissions permits. Lastly, there are (limited) water monitoring data.

There was discussion, in particular, about the Environmental Public Health Tracking Network (EPHTN) as a possible resource for exposure data, future data and proven data collection methodologies.[124] Workshop participants suggested that the EPHTN's Oil & Gas Work Group could develop nationally consistent measures for well emissions and a system of sentinel disease reporting. Several members of the Work Group were present at the meeting and agreed to bring the recommendations to the Work Group. Work Group members also invited workshop participants to serve as a "sounding board" of experts for the Tracking Network.

Lastly, participants discussed the value of looking to existing data collection efforts, not simply for the data they develop, but for the methodologies employed. The Center for Health and the Global Environment at Harvard, the Mid-Atlantic Center for Children's Health and the Environment, the Health Effects Institute, and the Natural Resources Defense Council are working on developing recommendations for environmental monitoring related to unconventional oil and gas extraction based on the outcomes of a December 2013 workshop of experts. Participants expressed an interest in receiving those recommendations once they are final.

3. Community Involvement And Data Collection

While not a path forward like a roster or data-mining endeavor, workshop participants were keenly aware of communities' stress and despair in areas where there is shale gas development. In addition, there was an appreciation that individuals' and community groups' knowledge, commitment, and on-the-ground resources (such as volunteers, organizers, and personal connections) can further the effort to understand the scope of the UNGD health effects problem. These perspectives were threaded through much of the discussion.

A workgroup tasked with thinking through community needs and involvement explained that communities are looking for the following:

- Action
- Industry Regulation
- Validation
- Voice
- Hope
- Knowledge
- Sense of trust

An appropriate and worthwhile registry must respond to what communities need. Community members must feel that they are a part of the process, and are not simply data points for researchers. They have a distinct and important role to play. Community advocacy groups and grassroots groups can serve as a link to a registry, particularly for individuals reluctant to reach out to state agencies or academic institutions, or who need to be convinced that the project is meaningful and productive. That said, some participants noted that other residents are mistrustful of advocacy groups and more trusting of state agencies. Community members and community groups can become leaders in the recruitment of participants and gathering of data. Resources for community action of this type exist and include FracTracker, EPA's Citizen Science Toolbox, and its Environmental Justice Toolbox.

When thinking about community involvement it is important to remain vigilant about communicating back to individuals and community groups. They are seeking knowledge that they can put to use. A registry can serve as a national forum for exchange of such information. This sharing of information can address (though not fully resolve) individuals' feelings of concern, despair, and anger. It can provide a step toward interventions and solutions.

VII. Conclusion: There are models, there are data sources, and there is need.

The intent of this paper is to bring to the fore the empirical evidence for UNGD emissions and health concerns near UNGD development sites. It is intended also to raise awareness of the types of health registries used for monitoring and addressing health concerns in other areas. Combined, these two pursuits became the foundation for a workshop of national experts who came together to examine whether a UNGD health registry is warranted or whether some other mechanism is needed to clarify the public health problem at hand. The workshop discussion led to three ideas which we hope can move beyond the experts in the room to experts, stakeholders and policymakers across the country. The ideas are: 1) create a roster of people who believe their health has been affected by UNGD; 2) use existing data and work with existing data-gathering efforts to investigate the characteristics and prevalence of UNGD health effects; and 3) ensure that whatever is created is responsive to the needs of all communities living daily with the harmful consequences of shale gas development.

Appendix A.

Case Definition
Health Effects Related to Unconventional Natural Gas Development (UNGD)
Environmental Exposures

A case definition is a set of uniform criteria used to define a disease for public health surveillance or epidemiological research. A case definition usually includes both an objective or laboratory criterion and clinical signs or symptoms which must be present to qualify as a case. Cases are classified as "suspected", "probable", or "confirmed" based on increasingly stringent criteria for being designated as a case. Case definitions are useful for estimating the magnitude of the health impacts of an exposure on a population. When in a clinical setting, due to the inherent sensitivity and specificity limitations (false negatives and false positives), a case definition should not be used as the only criterion when determining whether an individual is experiencing health effects related to an exposure.

Rationale

Case definitions for environmental exposures typically require an indicator for the environmental exposure in addition to clinical signs and symptoms compatible with the exposure. In the current case definition, an actual measured exposure to a contaminant provides the most stringent exposure indicator, and is required to meet the criteria for a confirmed case. As in other studies, in the absence of a measured exposure, proximity to one or more exposure sources is used as a surrogate. Presence within 1 km of facilities extracting, transporting, processing or storing UNGD gas or waste, is required for a probable case, and within 1-2 kilometers for a suspected case. Examples of "a presence" include residing, working, or attending school. The case definition is not intended to address the occupational exposures of individuals working within the shale gas industry.

The Southwest Pennsylvania Environmental Health Project (EHP) case definition for health effects related to environmental exposures from UNGD activities is primarily derived from the knowledge gained from EHP's health assessments of over 80 individuals in southwest Pennsylvania with potential exposure to UNGD related air and water contaminants. The observations of several physicians outside of EHP with experience evaluating residents with UNGD related exposures were also incorporated into the case definition. The case definition takes into account the recognized short term health effects of both the ubiquitous air emissions (volatile organic compounds, formaldehyde, and particulate matter), as well as the more sporadically occurring water contamination. The case definition also recognizes that based on both source characteristics and weather variables, exposures, and therefore symptoms, may be episodic, persistent, or transient.

The case definition includes only the acute health effects experienced by residents exposed to UNGD contaminants. Exposure to many of the contaminants responsible for the short term symptoms also increase the risk for serious long term adverse health consequences, such as chronic respiratory disease, chronic neurologic dysfunction, and cancer.

Residents living in proximity to shale gas activities frequently report the new onset of psychological symptoms that interfere with normal functioning, including anxiety, depression, fatigue, behavior changes, difficulty focusing and feeling a loss of control. Although it is important to recognize and to address these disabling symptoms they were not included in the case definition , as they may often be attributable to other circumstances associated with shale drilling, rather than the environmental chemical exposures.

Criteria for a Confirmed Case of Health Effects Related to Shale Drilling Environmental Exposures	
Environmental Exposure	**A documented* air and/or water exposure to an emission or contaminant originating from a shale gas site.** ***Instrument or laboratory measured air contaminant. Laboratory confirmed water contaminant***
AND	
Clinical Signs or Symptoms	**The development of signs or symptoms or worsening of pre-existing signs or symptoms from two or more of the following systems:** **1. Respiratory (cough, shortness of breath, throat soreness or irritation, sinus problems, or nosebleeds.)** **2. Dermal (rash, pruritus, or irritation.)** **3. Neurological (headache or dizziness)** **4. Gastrointestinal (nausea or abdominal pain)** **Relevant signs or symptoms must occur after the onset of potential shale gas exposures and must be without a more plausible explanation (such as an unrelated exposure, pre-existing medical condition (unless exacerbated), or intercurrent illness). New or worsening symptoms may be episodic, persistent or transient.**
Criteria for a Probable Case of Health Effects Related to Shale Drilling Environmental Exposures	
Environmental Exposure	**A presence for a period of at least 20 hours/week during a minimum of at least one month within one kilometer of one or more facilities extracting, transporting, processing or storing shale gas or waste.**
AND	
Clinical Signs or Symptoms	**The development of signs or symptoms or worsening of pre-existing signs or symptoms from two or more of the following systems:** **1. Respiratory (cough, shortness of breath, throat soreness or irritation, sinus problems, or nosebleeds.)** **2. Dermal (rash, pruritus, or irritation.)** **3. Neurological (headache or dizziness)** **4. Gastrointestinal (nausea or abdominal pain)** **Relevant signs or symptoms must occur after the onset of potential shale gas exposures and must be without a more plausible explanation (such as an unrelated exposure, pre-existing medical condition (unless exacerbated), or intercurrent illness). New or worsening symptoms may be episodic, persistent or transient.**
Criteria for a Suspected Case of Health Effects Related to Shale Drilling Environmental Exposures	
Environmental Exposure	**A presence for a period of at least 20 hours/week during a minimum of at least one month within one to two kilometers of one or more facilities extracting, transporting, processing or storing shale gas or waste.**
AND	
Clinical Signs or Symptoms	**The development of signs or symptoms or worsening of pre-existing signs or symptoms from two or more of the following systems:** **1. Respiratory (cough, shortness of breath, throat soreness or irritation, sinus problems , or nosebleeds.)** **2. Dermal (rash, pruritus, or irritation.)** **3. Neurological (headache or dizziness)** **4. Gastrointestinal (nausea or abdominal pain)** **Relevant signs or symptoms must occur after the onset of potential shale gas exposures and must be without a more plausible explanation (such as an unrelated exposure, pre-existing medical condition, (unless exacerbated), or intercurrent illness). New or worsening symptoms may be episodic, persistent or transient.**

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