CRITICAL REVIEW:
RECENT STUDIES OF PUBLIC EXPOSURE AND HEALTH RISKS FROM SHALE GAS DEVELOPMENT AIR EMISSIONS

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BACKGROUND

A number of factors are driving a need to better understand the actual exposures and potential health risks of air emissions from natural gas operations. One factor is the rapid growth of shale gas development in the United States. Another is federal and state initiatives to monitor and regulate these air emissions. In December 2014, USEPA issued *Oil and Natural Gas Sector: Reconsideration of Additional Provisions of New Source Performance Standards* providing clarifications and updated regulations for well completions, storage tanks and natural gas processing plants. In January 2015, the Obama Administration released a fact sheet outlining plans to further reduce emissions of methane and VOCs from the natural gas industry. An important question will be: how much reduction is enough to protect against unacceptable levels of health risks? It is necessary to understand sources and magnitudes of exposure and risk to determine when additional spending on emission controls is not cost-effective in further reducing health risks. Simply trying to engineer an emission-free operation is cost-prohibitive and a threat to shale gas development economics. USEPA has also recently proposed to make shale gas facilities subject to the Toxic Release Inventory reporting requirements.

On a more regional level, in the Marcellus Shale area the Allegheny County Health Department has added two air monitoring sites near unconventional well activity. Air monitoring at these sites, which began in March 2014, includes 24-hour grab samples taken once every 6 days at one site, and one sample every 14 days at the second site. Sampling started before initial well site preparation and is continuing through the drilling, hydraulic fracturing, and well completion. Data from the monitors is posted on their website as it becomes available, and is compared to EPA reference concentrations and carcinogenic classifications. The chemicals reported include selected VOCs, naphthalene, and nitrogen dioxide. The comparisons have the potential for significant misinterpretation by the public.

There is also a potential legal factor that may increase the need to better understand exposures to air emissions from shale gas operations. Claims of adverse health impacts in an area where chemicals may be transported widely in air from a source have the potential to develop into a class action law suit. But according to the Class Action Fairness Act of 2005 (CAFA), class actions are governed by Rule 23 of the Federal Rules of Civil Procedure. Under recent rulings, proving compliance with Rule 23 requires heightened evidentiary proof, and without it the class action can be de-certified. One of the proofs required is "commonality", where for example, showing that the plaintiffs were not exposed to the same amount can result in de-certification. Another proof required is "causation", where inability to prove a causal connection between exposure and claimed health effects (common to the plaintiff group) can result in de-certification. The use of meteorological data, varying concentrations over time, varying exposures over time and space, realistic estimates of exposure as a function of time, and comparison of claimed health effects to toxic effects scientifically related to the detected chemicals, can all be useful to address these lines of proof should litigation develop.

CRITICAL REVIEW

There have been a number of recent studies, some published in peer-reviewed journals, purported to assess public exposure and health risks from shale gas development-related air emissions. There are significant problems with the methods used in some of these studies, and inappropriate conclusions have been stated by the authors. Nevertheless, the media have regularly and repeatedly used these studies, resulting in misperception of the risks associated with shale gas development. In general, the key problems with a number of these studies are:

- They make conclusions about health risks without actually assessing risks or using accepted quantitative risk assessment methodologies. Often inappropriate comparisons of measured concentrations to ambient air quality standards are used to characterize health risks;
- They characterize potential exposures using biased (high) point-in-time measures of air concentrations which are assumed to occur over many years, rather than measuring concentrations as a function of time and duration of activity to develop correct integrated exposure estimates;
- They assume chemicals detected have originated from shale gas operations when they may be from other sources
- They use inappropriate monitoring techniques and have poor quality control and data validation; and
- They claim real or perceived health effects that may not correspond to the known toxic endpoints of chemicals detected.

It is important to understand these shortcomings, as well as the good elements of available studies, so that misperceptions of health risks are not perpetuated, improved studies can be designed and implemented, and an appropriate basis for decision-making is developed.

A critical summary of some of the recent published studies is presented below. First are some studies that have some challenges.

1. ***Air Concentrations of Volatile Compounds near Oil and Gas Production: A Community-Based Exploratory Study*** by Greg P. Macey (Brooklyn Law School) et al. in Environmental Health, Volume 13, 2014.

   In this study, canister air samples were collected by "trained" residential volunteers at locations identified by observation of shale gas operations. A total of 75 volatile organics were measured. Levels of eight volatile chemicals from point-in-time grab samples were inappropriately compared to ambient air quality standards that are based on long-term exposure and EPA reference concentrations that are based on chronic exposure durations. In addition, sampling was done in a biased manner because they were grabbed when operations were (a) observed to likely have peak emissions, or (b) when the person sampling felt symptoms such as dizziness, nausea or headaches.

   Benzene, formaldehyde, and hydrogen sulfide were the primary compounds identified of concern.

   This study uses a biased methodology to make inappropriate conclusions about potential health risk. It is published in a journal in the guise of scientific credibility, and was peer-reviewed by known anti-fracking activists. Nonetheless, the authors have been cited and quoted many times by the media with statements including:

   - *The study showed that oil and gas wells were spewing carcinogens into the air, posing "a significant public health risk" that made an "elevation in cancer … almost certain to happen," according to lead researcher David Carpenter (University of Albany)*
   - *"I was amazed," Carpenter says. "Five orders of magnitude over federal limits for benzene at one site – that's just incredible. You could practically just light a match and have an explosion with that concentration.*
   - *"The way fracking's being done in these five states, it's not being done safely," Carpenter says. "It's an indication of how leaky these systems are."*

   Most of the co-authors of this study are affiliated with environmental activist organizations, and the authors acknowledge contributions from several known anti-fracking organizations.

2. ***Proximity to Natural Gas Wells and Reported Health Status: Results of a Household Survey in Washington County, Pennsylvania*** by Peter M. Rabinowitz (Yale University) et al. in Environmental Health Perspectives, National Institute of Environmental Health Sciences, September 2014.

In this study, people living near oil and gas wells were paid to complete a survey about health symptoms. The study concludes that people in Washington County, Pa., who live within a kilometer of oil and gas wells, suffer from more respiratory and skin conditions than those who live farther away. The researchers hypothesize that this is because oil and gas wells could be impacting private water wells and air quality, including "volatile organic compounds, particulates, and ozone from upwind sources, such as flaring of gas wells and exhaust from vehicles and heavy machinery."

Many scientists see major flaws in this study. For example, Dr. Ian Rae, a co-chair of the Chemicals Technical Options Committee for the U.N. Environment Programme, stated "It certainly does not qualify as a scientific paper but is, rather, an advocacy piece that does not involve deep…analysis of the data gathered to support its case." It is notable that the study received funding from the Heinz Endowment, and members of the Southwest Pennsylvania Environmental Health Project assisted with the community survey. Both organizations have taken positions against shale gas development.

Nonetheless, the study has been cited frequently as evidence of a causal relationship between health impacts and shale gas activities in the Marcellus Shale region.

3. ***Impact of Natural Gas Extraction on PAH Levels in Ambient Air*** by L. Blair Paulik et al. (Oregon State University and University of Cincinnati) in Environmental Science & Technology, Vol. 49, 2015.

   The researchers used low density polyethylene (LDPE) samplers to passively sample vapor phase PAHs in air at the properties of 23 volunteers located in Carroll County, Ohio. Sampling was grouped by distance from the closest active well pad, and designated as "close" (0.1 mile), "middle" (from 0.1 to 1 mile), and "far" (from 1 to 3.2 miles). Isomer ratios were used to determine if the PAH vapor was petrogenic (from the earth) or pyrogenic (from combustion). Petrogenic determinations were assumed to be from well pad operations. USEPA relative cancer potency for benzo[a]pyrene equivalents were applied to air sample results to estimate cancer risk for hypothetical residents and outdoor workers, using upper bound exposure assumptions. Benzo[a]pyrene, fluoranthene, and benzo[b]fluoranthene were found to be the main contributors to cancer risk estimates.

   The study suggests conclusions that are beyond the limitations of the methodology and results. The authors state that risk estimates decrease 30% when comparing results from samplers from the "close" group to the "far" group. Within the limitations of cancer risk estimation, 30 percent is not significant. While, as they indicate, going from 12 to 8.1 in a million excess lifetime cancer risk is about a 30% difference, risk assessors and risk managers would see minor difference between 8E-06 and 12E-06, especially with one standard deviation error bars that overlap for risk estimates between distance groups, and $\pm$20% verification range for sample analytical results. Furthermore, the exposure assumptions used (resident = 26 years of exposure for 350 days per year; outdoor worker = 25 years of exposure for 225 days/year) are unrealistically high end. There are a number of other limitations in this study, including: (1) sampling locations were based on available volunteer properties and not on data quality objectives, (2) samples were taken, packed and shipped (from Ohio to a laboratory in Oregon) by residential volunteers, (3) specific well pad operations occurring during the 3-4 week sampling duration do not appear to have been incorporated into integrated exposure estimates, and (4) no attempt appears to be made to determine specific sources of PAH emissions beyond generalizing from isomer ratios

4. ***Understanding Exposure From Natural Gas Drilling Puts Current Air Standards To The Test*** by David Brown et al. (Southwest Pennsylvania Environmental Health Project) in Review of Environmental Health, 2014.

   A case study is presented to support a position that the type of acute health effects observed near unconventional natural gas development (UNGD) sites are not properly addressed by current air

quality monitoring protocols or standards. The paper states that the intensity, duration and frequency of exposures are not being sufficiently characterized for accurately assessing risks to individuals near UNGD sites. The study concludes that the typically used periodic 24-hour average measures can underestimate actual exposures by an order of magnitude and that local weather conditions are strong determinates of individual exposures. It calls for new protocols to provide 1) continuous measures of a surrogate compound to show periods of variable exposure; 2) continuous meteorological monitoring to correlate with exposures; and 3) detection of multiple chemicals using canisters or other devices that capture the major components of emissions.

While I do not concur with conclusions regarding observed acute health effects, in general, I do not disagree with these recommendations. However, I do disagree that implementing better methods to determine exposures integrated over time will result in higher exposure estimates. Including times when concentrations are low or non-detect will likely lower estimated exposure estimates.

5. ***An Exploratory Study of Air Quality near Natural Gas Operations*** by Theo Colburn et al. in Human and Ecological Risk Assessment: An International Journal, Volume 20, Issue 1, 2014.

   In this study, 4-hr (10AM to 2PM) and 24-hr air sampling was conducted every 7 days from a fixed sampling station located 0.7 mile from a well pad on which 16 vertical (directional) gas wells had been drilled. Interstate 70 is one mile from the sampling location, and there were 130 wells producing natural gas within 1 mile of the sampling site at the time of the study. In addition, two other well pads were developed using vertical drilling within 1 mile of the sampling site within the timeframe of the study. Sampling was done before, during, and after drilling and hydraulic fracturing.

   The study included a literature search of the health effects of chemical detected, regardless of concentration, frequency or source. It states that 30 chemicals can affect the endocrine system and states a concern over PAH exposures by children. It further concludes that, while the concentrations at which chemicals were detected in the air are far less than NIOSH Recommended Exposure Limits and OSHA Permissible Exposure Limits, these standards are not protective of exposure scenarios faced by individuals experiencing chronic, sporadic, low-level exposure, 24 hours a day 7 days a week in natural gas neighborhoods.

   These statements are quite a reach from the scope and limitations of the study. The extrapolation of health concerns assuming chronic 24 hour/day, 7 day/week exposures is inappropriate, based on just the presence of chemicals and samples taken once per week at a single location with multiple potential sources. There is not proper data from this study to support the conclusion, and applying occupational standards to assessment of chronic off-site exposures is inappropriate. Furthermore, "sporadic" exposures do not occur "24 hours a day 7 days a week".

There have also been several more carefully-designed studies with more attention to the quality of technical methodologies used to measure air quality related to shale gas operations and estimate the potential health risks. These are helpful to consider when designing a meaningful, technically correct study.

1. **Evaluation of Impact of Shale Gas Operations in the Barnett Shale Region on Volatile Organic Compounds in Air and Potential Human Health Risks** by A.G. Bunch (ToxStrategies) et al. in Science of the Total Environment, 468-469 (2014).

   Regional monitoring data for hundreds of VOCs were compared to state and federal health-based air comparison values to assess potential acute and chronic health effects. The results demonstrated no exposures that would pose a health concern to the community. These findings are regional and not local.

The significant and relevant VOCs identified by the study include: benzene, ethylbenzene, m/p-xylene, o-xylene, n-hexane and toluene.

This study was funded by the Barnett Shale Energy Education Council (BSEEC), a consortium made up of: Chesapeake Energy, Devon, Enervest, EOG Resources, XTO Energy, Western Production, Atlas, Pioneer Natural Resources, Newark Energy, Beacon E&P, Access Midstream and FTS International. Therefore, an argument can be made that a study funded by gas industry members may be as subject to potential biases as one funded by anti-fracking activist groups. However, care appears to have been exercised in use of an objective technical approach.

2. ***Human Health Risk Assessment of Air Emissions from Development of Unconventional Natural Gas Resources*** by Lisa M. McKenzie (Colorado School of Public Health) et al. in Science of the Total Environment (2012).

   Air sampling data from 2008 to 2012 in Garfield County, Colorado were used in a standard USEPA risk assessment to estimate non-cancer hazard indices and excess lifetime cancer risks from inhalation exposure to hydrocarbons by residents living > 0.5 mile and < 0.5 mile from well pads and natural gas development areas. Assumptions were made about exposure durations during different stages of well development and operations. Chronic hazard indices and cancer risk estimates were within acceptable ranges. Sub-chronic hazard indices within 0.5 mile (HI=5) were estimated to be above the acceptable non-cancer health risk goal of 1. Samples were analyzed for 78 hydrocarbons.

   The significant and relevant VOCs identified by the study include: 1, 2, 4-trimethylbenzene; 1, 3, 5-trimethylbenzene; benzene; xylenes; aliphatic hydrocarbons C_9 – C_{18}; 1, 3-butadiene; and ethylbenzene.

3. ***City of Fort Worth Natural Gas Air Quality Study*** by Eastern Research Group and Sage Environmental Consulting, prepared for City of Fort Worth, July 13, 2011.

   Single ambient air monitors were located at sites around the city, predominantly downwind of locations selected to represent air quality from background, highways, hydraulic fracturing and flowback operations, multiple pad and compressor operations, and at well pad setbacks (fence lines). 24-hour average canister samples were collected once every three days at these sites and analyzed for VOCs and carbonyls.

   The key pollutants detected were acrolein, acetalhyde, benzene, 1,3-butadiene, carbon tetrachloride, p-dichlorobenzene, formaldehyde, and tetrachloroethylene.

   Based on comparison to state standards for acute exposure durations, the ambient air monitoring data provide no evidence of 24-hour average concentrations reaching levels of health concern. Concentrations were also averaged over the entire program dataset, and these average concentrations (representing two months of potential exposure) were below longer-term Texas health-based screening levels.

   The study also included point source measurements of equipment emission rates at well operations. These were input to air dispersion models. When model results were compared to the ambient air quality data, even the highest emissions from well pads and compressor stations did not account for the levels measured in the ambient air. The modeling predicted that of all pollutants considered, only acrolein, benzene, and formaldehyde had estimated 1-hour average concentrations greater than TCEQ's short-term standards. Modeling of annual average air quality impacts using maximum emission rates measured at well pads and compressor stations showed only acrolein and formaldehyde with estimated annual average concentrations at locations at least 200 feet from fence lines greater than TCEQ screening levels.

4. ***Community Health Risk Analysis of Oil and Gas Industry Impacts in Garfield County*** by Teresa Coons, Ph.D. (Saccomanno Research Institute) and Russell Walker, Ph.D. (Mesa State College) 2008.

   Risk was evaluated for human exposure to pollutants associated with natural gas operations in air, water, and soil in Garfield County. A general lack of data on pollutant concentrations in the environment limited the assessment. With respect to air, pollutant concentrations were generated through a mathematical model to supplement the concentrations sampled by Garfield County. A Gaussian plume model was used to make a plausible prediction of air pollutant concentrations that may occur during natural gas operations. The model was based, to the degree possible, on the meteorological conditions specific to Garfield County, and was applied to five specific natural gas operations: flow back during well completion with no recovery of natural gas, flow back with 93% recovery of natural gas, wellhead glycol dehydration, uncontrolled emissions from condensate tanks, and condensate tank emissions controlled by a combustion device. The pollutant concentrations generated by the model were then used in risk calculations based on the USEPA's risk assessment guidance.

   The results of the risk assessment indicate that the USEPA's acceptable value for cancer risk can be exceeded for benzene in air assuming a 70-year exposure. Benzene emissions during uncontrolled flow back indicated the greatest cancer threat. However, the authors admit that risk of cancer exceeds the EPA acceptable range only for a 70-year exposure and an exposure of that duration to uncontrolled flow back is unlikely.

5. ***Estimation of Regional Air-Quality Damages from Marcellus Shale Natural Gas Extraction in Pennsylvania*** by Aviva Litovitz et al. (RAND Corporation) in Environmental Research Letters, Vol. 8, 2013.

   An emission factors approach was used to develop first-order estimates of regional emissions from Marcellus Shale gas extraction activities in Pennsylvania. The analysis included: diesel and dust emissions from trucks; emissions from well drilling and hydraulic fracturing, including diesel combustion; emissions from production, including on-site diesel combustion and fugitive emissions; and combustion emissions from natural gas-powered compressor stations. Pollutant emission estimates were developed for: VOCs; NO_x; particulate matter; and SO_2. The Air Pollution Emission Experiments and Policy model (APEEP) was used to estimate age-specific health damages, among other costs, in financial terms.

   An interesting finding was that most estimated emissions are related to on-going activities, such as gas production and compression, and not well development. More than half of the estimated costs related to air quality impacts came from compressor stations. The authors recommend future analyses that include regional air quality data acquisition combined with consideration of site-specific variability.

6. ***Air Pollutant Emissions from the Development, Production, and Processing of Marcellus Shale Natural Gas*** by Anirban Roy et al. (Carnegie-Mellon University) in Journal of Air & Waste Management Association, Vol. 64, 2014.

   An air emissions inventory is developed for gas development, production and processing activities in the Marcellus Shale region. Emissions are estimated using process-specific emission factors for 2009 and projected to 2020. The 2020 emissions are projected assuming three different levels of air emission controls. The inventory estimates NO_x, $PM_{2.5}$, and total VOC emissions from drilling, hydraulic fracturing, completion venting (flowback), compressors and truck traffic. Emission estimates from equipment/sources are developed for one well and one unit of downstream gas processed, then combined with Marcellus region basin-level activity to estimate overall Marcellus-wide emissions. Uncertainties are treated quantitatively in the estimation methodology.

This process-based approach is necessary because many (if not most) activities and equipment do not have measured emission rates. However, significant uncertainty using this approach comes from activity data (such as truck distance travel, number and rating of engines, engine on-time, load factor versus time on drill rigs, volume of gas vented, etc.) as well as emission factor estimates. It is technically possible to use the results of this study as input to air quality modelling, then use model results to estimate exposures and risks from the three broad categories of emission factors developed. However, uncertain assumptions would be required about source locations, activities, and emission timing. In addition, the emission estimates are aggregate (e.g., total VOCs) and do not include potentially key toxic air components (e.g., PAHs).