Association between Elevated Airborne Radioactivity and Natural Gas Emissions Downwind of a Colorado Oil Refinery

D. Helmig[1,*], J. Nobel[2], D. Caputi[1,3], D. Brown[4], R. Daly[1], L. Darby[1, 5], P.T. Doe[6], O. Gonzalez[7], G. Greenberg[1, 8], J. Hueber[1], K. Potter[1, 9], G. Schade[10], S. Simoncic[1, 11], M. Stahli[1, 12], and W. Subra[13]

[1]Boulder A.I.R. LLC, Boulder, CO 80305; [2]Rolling Stone Magazine, New York, NY, 10017, [3]Planet Ozone Meteorological Consulting, Concord, CA 94521, [4]Environment and Human Health Inc., Westport, CT 06880, [6]LDWX LLC, Boulder, CO 80301, [7]Be the Change – Colorado, Littleton, CO 80218, [7]Cultivando, Commerce City, CO 80614, [8]Boulder, CO 80303, [9]Kateric Ltd, Longmont, CO 80501, [10]Texas A&M University, Department of Atmospheric Sciences, College Station, TX 77843, [11]Pitch Roll and Yaw LLC, Boulder, CO 80302, [12]Fort Collins, CO 80525, [15]Subra Company, New Iberia, LA 70562
*E-mail: dh.bouldair@gmail.com

SUMMARY

There is no safe level of radon exposure. A 16% increase in lifetime lung cancer risk is estimated for every 100 Bq m^{-3} increase in airborne radioactivity [1]. The EPA estimates 21,100 lung cancer deaths per year in the US due to radon inhalation [2]. Oil and gas production brings to the surface significant amounts of radon, an odorless radioactive gas produced from the radioactive decay of U-238 and Th-232 in the fuel-bearing shale formations. Downwind of hydraulic fracturing (fracking) wells, airborne radioactivity has previously been found to be seven times higher than for conventional oil and gas wells [3]. Here, we report year-long, 10-min resolution monitoring results of radon gas and radon progeny attached to particulates in a disproportionally impacted environmental justice community northeast of the Suncor oil refinery in Commerce City, Colorado, USA. Elevated airborne radioactivity tracked closely with the natural gas tracer ethane. Total radioactivity levels of 30–40 Bq m^{-3} were 2–3 times higher than background levels (~10–15 Bq m^{-3}) when winds were light and southwesterly, suggesting the refinery as the origin. To date, U.S. regulatory agencies do not require assessment for oil and gas industry radioactivity emissions, even though radon is regarded as a hazardous air pollutant and is enforceable under the Clean Air Act. Our findings suggest a need for characterizing radon emissions from oil and gas well sites and related infrastructure and operations such as natural gas processing plants, compressor stations, petrochemical plants, and oil refineries, in particular those that process petroleum hydrocarbons from unconventional oil and gas extraction.

RADIOACTIVITY OCCURRENCE (I)

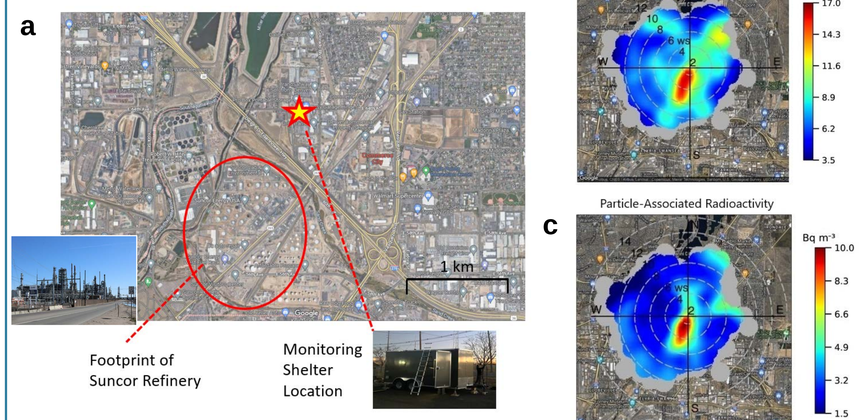


Figure 2. (a) Location of the Commerce City Fixed (CCF) monitoring site (yellow star), ≈0.7 km north of the boundary of the footprint of the Suncor Refinery (red circle). (b, c) Bivariate polar plots of the dependency of gas-phase (b), 30 Aug 2022 – 2 Aug 2023, and particle-associated (c), 2 Oct 2022 – 2 Aug 2023, airborne radioactivity as a function of wind speed (m s^{-1}) and wind direction; color scale indicates the observed median radioactivity for a given wind speed and direction. The wind analysis is overlaid on a map centered at CCF. Note the different scales of the color bars.

RADIOACTIVITY OCCURRENCE (II)

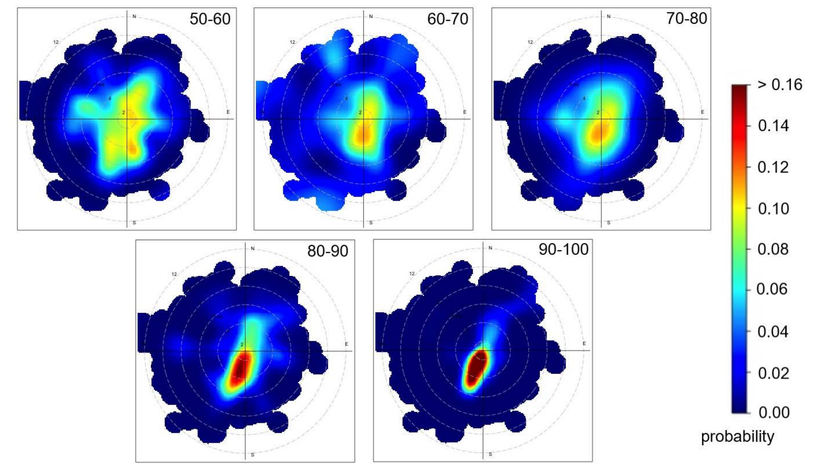
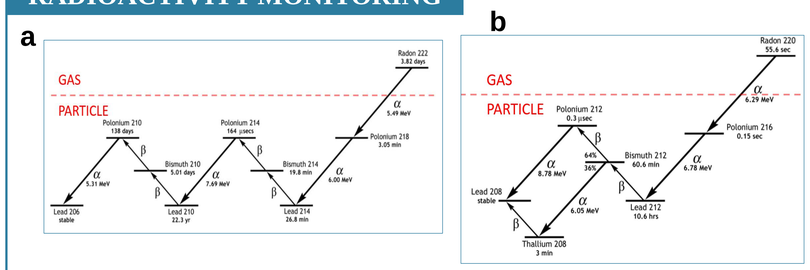


Figure 4. Probability distribution of the gas-phase radioactivity on wind speed (m s^{-1}) and direction separated by 10-percent percentile bins (as labeled). The prevalence of transport from the direction of the Suncor Refinery becomes progressively more pronounced for the higher values of the monitoring data distribution.

RADIOACTIVITY MONITORING



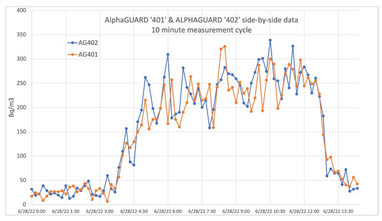


Figure 1. (a) Radioactive decay and progenies of radon-222. Radon-222 itself is the decay product of thorium-234 and uranium-238 and the most abundant radon isotope in the atmosphere. It has a lifetime of 3.8 days and can be transported with natural gas from geologic formations to the surface and remain in natural gas or the atmosphere for several days. Its decay products are non-volatile and will attach to particles. (b) Decay of radon-220 (also named thoron). Its lifetime is much shorter, on the order of a minute. Similar to radon-222, decay products are also non-volatile and adhere to particulates. (c) Bertin Technologies AlphaGuard DF-2000 radon gas alpha radioactivity monitor. (d) AlphaPM monitor for detection of particle-associated alpha-radiation of radon progenies. (e) Results from running two AlphaGuard monitors side-by-side in a Longmont residential home basement showing good agreement between the two measurements.

RADIOACTIVITY ATMOPSPHERIC BEHAVIOR

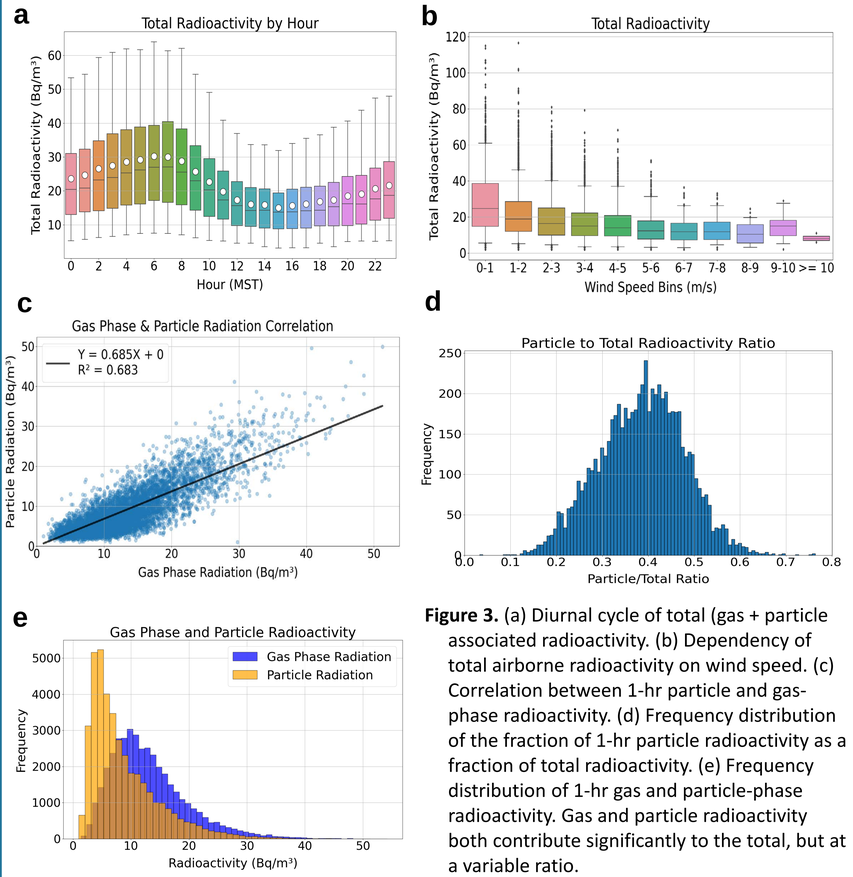
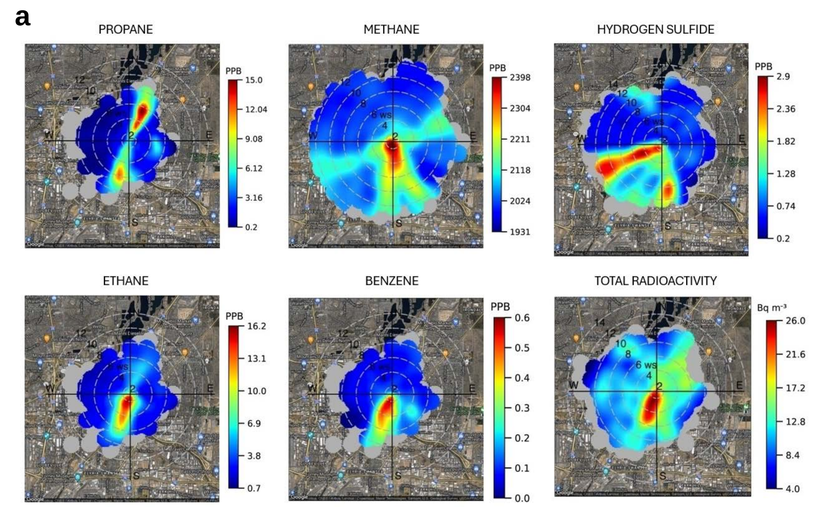


Figure 3. (a) Diurnal cycle of total (gas + particle associated radioactivity. (b) Dependency of total airborne radioactivity on wind speed. (c) Correlation between 1-hr particle and gas-phase radioactivity. (d) Frequency distribution of the fraction of 1-hr particle radioactivity as a fraction of total radioactivity. (e) Frequency distribution of 1-hr gas and particle-phase radioactivity. Gas and particle radioactivity both contribute significantly to the total, but at a variable ratio.

RADIOACTIVITY CORRELATIONS



b

Species	Residual Variance 10 min	50 min	60 min
Gas Phase Radioactivity	0.139		
Particle Radioactivity	0.152		
Carbon Dioxide	0.416		0.293
Ethane	0.425	0.319	
Nitrogen Oxides	0.515		0.383
Carbon Monoxide	0.408		0.383
Methane	0.560		0.426
Benzene	0.611	0.533	
i-Butane	0.604	0.534	
n-Butane	0.689	0.632	
Hydrogen Sulfide			0.640
Toluene	0.728	0.677	
Propane	0.875	0.850	

Figure 5. (a) Side-by-side comparison of the dependency of propane, methane, hydrogen sulfide, ethane, benzene, and total radioactivity on wind speed (m s^{-1}) and direction. (b) Residual variances for orthogonal distance regression (ODR) correlations between total radioactivity and indicated species, ranked by correlation strength (1 minus residual variance). Highest correlation is seen with carbon dioxide, carbon monoxide, and the natural gas tracer ethane, suggesting a possible association of radioactivity emissions with a natural gas and/or natural gas flaring source.

1] Darby, S., et al. (2005) Radon in homes and risk of lung cancer: collaborative analysis of individual data from 13 European case-control studies, BMJ 330, 223; [2] US-EPA (2003) EPA Assessment of Risks from Radon in Homes, www.epa.gov/sites/default/files/2015-05/documents/402-r-03-003.pdf; [3] Li, L. et al. (2020) Unconventional oil and gas development and ambient particle radioactivity, Nature Communications 11, 5002.