Public Health Assessment for Airborne Emissions from the Bristol, Virginia, Landfill: a Preliminary Report

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INTRODUCTION AND OVERVIEW

Many residents of Bristol, Tennessee (and of their sister city, Bristol, Virginia) have been experiencing unusually offensive odors emanating from the municipal solid waste (MSW) landfill in Bristol, VA. This preliminary[1] report seeks to estimate whether these emissions also pose significant risks to these residents' long-term health.

As is well known, the biodegradation of MSW (whether in landfills, in composting areas, or even in transfer stations, prior to further treatment) necessarily involves the production of malodors; and when people live close to poorly designed and/or poorly controlled MSW landfills, their well-being may well be compromised (Vinti et al., 2021). There is little doubt that the public's quality of life and well-being have been compromised by airborne emissions from the Bristol VA landfill.[2] This is largely because malodors from the Bristol VA landfill are apparently more intense, more noxious, and more persistent than might otherwise be expected and/or tolerated.[3]

In what follows, we offer a preliminary assessment as to whether the airborne landfill emissions are posing not only risks to people's quality of life and well-being, but risks to their long-term physical health as well.

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[1] Please note that results from neighborhood air-sampling performed this past October, by contractors for U.S. EPA, are not yet available to us. Accordingly, please consider this report to be preliminary. We will issue an additional report after we have received and analyzed the October 2021 dataset.

[2] Pets and other animals' well-being and health may also be being compromised by landfill emissions. For example, cats may be much more sensitive than people to various odors — even to odors that most people find to be pleasant, let alone those that are unpleasant. In reaction to strong odors, some cats may experience nausea, anorexia, and/or related problems. Other outdoor cats, however, may hunt at waste-sites for rodents and food wastes. This makes it difficult to determine whether the landfill at issue has or has not harmed outdoor cats.

[3] In contrast to ambient air, drinking water sources are not known to have been affected by the landfill. Notably, though, it appears that an underground plume of gasoline (or similar material) has contaminated groundwater that *is leaking **into** the quarry*, which (as so-called "gradient water") is then being mixed in with the landfill leachate, resulting in elevated concentrations of benzene in combined aqueous effluents that are conveyed to the wastewater treatment facility in Bristol, TN.

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We turn first to the topic of malodors, and then address risks to people's health from benzene and other potentially hazardous air pollutants, separate and distinct from adverse health effects due to odors *per se*.

EFFECTS OF MALODORS

In general, malodors — whether from landfills or other sources, such as sewage treatment plants, paper mills, other industrial complexes, or large poultry and livestock operations — can engender signs and symptoms such as nausea, headaches, psychological stress; and, in at least some individuals, additional, adverse effects engendered by such stress (Sucker et al., 2001; Karl et al., 2018; Guadalupe-Fernandez et al., 2021). This may be true both for people and for other animals, including pets.

With regard to landfills in particular, Heaney and colleagues (2011) conducted a small study centered on a malodorous landfill in Orange County, North Carolina. They focused on environmental injustice, introducing their study as follows:

> *Since 1972, the historically African-American Rogers-Eubanks community in Orange Co., North Carolina, has hosted a number of waste facilities including, most recently, a Subtitle D municipal solid waste landfill. For several decades community members have been concerned about impacts of these waste facilities on their health and quality of life. The purposes of this study, conducted in the Rogers-Eubanks community, are to measure levels of hydrogen sulfide (H_2S), a gas generated by anaerobic decomposition of organic wastes in landfills (ATSDR, 2010), track the occurrence of odors reported by community members, and evaluate relationships between H_2S exposure, reports of malodor, alterations of daily activities, mood states, and physical symptoms.*

Unfortunately, their study was limited by design (it relied on self-reported symptoms and used study-subjects as their own controls) and by its small size (only 23 study subjects), so that the generalizability of their findings is quite limited. Nonetheless, the investigators reported significantly increased risks of: (i) self-reported, upper respiratory symptoms (with an odds ratio [OR] of 3.9, and a 95% confidence interval [CI] of 2.2 to 7.0); (ii) alterations of daily activities (OR, 9.0; 95% CI = 3.5 to 23.5); and (iii) negative mood states: 5.2 (2.8, 9.6). Complaints of malodors only weakly correlated with contemporaneous measurements of hydrogen sulfide (H_2S) in ambient air in the neighborhoods whence came the complaints. This finding, which was contrary to the investigators' expectations, is indicative of the complexities associated with both designing and interpreting studies of environmental odors and public health.

Kret and coworkers (2018) conducted a much larger "respiratory health survey" of residents proximate to a "subsurface smoldering landfill" in Bridgeton, Missouri, and of matched controls. They conducted "face-to-face interviews of residents both near the landfill and away

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from the landfill, focused mainly on respiratory symptoms and diseases such as asthma and chronic obstructive pulmonary disease."

The investigators found no significant differences with regard to the prevalence of respiratory diseases *per se*, but did find that:

> *Landfill households reported significantly more "other respiratory conditions," (17.6%, 95% CI 11.1–24.1 landfill vs 9.5%, 95% CI 4.8–14.3 comparison) and attacks of shortness of breath (33.9%, 95% CI 25.1–42.8 landfill vs 17.9%, 95% CI 12.3–23.5).*

As expected, "Frequency of odor perceptions and level of worry about neighborhood environmental issues was higher among landfill households ($p < 0.001$)."

More generally, the authors note:

> *…attempting to assess the health effects from landfills is beset with methodological problems including the ability to measure for actual exposure and then adjusting for covariates … However … [R]esidents near the landfill have a significantly higher perception of odor and a concern about environmental issues that need to be addressed as well.*

The malodors from MSW landfills are generally due to sulfurous compounds such as hydrogen sulfide and methyl mercaptan (also known as methanethiol, the odorant added to natural gas, with a smell reminiscent of rotten eggs or rotten cabbage), mixed with other odorous compounds (such as volatile products of the biodegradation of fatty acids and proteins in foodwastes), so that emitted odors vary from time to time, and from place to place. Further complicating matters, we people vary among ourselves in terms of both how we perceive odors, and in how we react to them.

The odor complaint descriptions indicate this is true for this landfill. Humans (and other animals) are extremely sensitive to these odors, with most people being able to detect them at part-per billion concentrations and lower.

The U.S. EPA monitoring in June and July 2021 occasionally detected hydrogen sulfide for short periods at levels that varied from 1 to a maximum of 11 parts per billion (ppb), easily detectable by nose; and there are likely other even more malodorous compounds present. Notably, the airborne concentrations that have been measured are well below those at which these compounds can directly cause lasting health effects.

An onsite sampling program, conducted by Trinity Consultants Inc., on November 16, 2021, identified several sources of distinctive odors at the Bristol VA landfill. Four landfill sites, and a

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compost area near the landfill, were investigated, with samples of ambient air collected near each site. Intense odors were detected at three of these five locations.

First, odors from the leachate tank were characterized (by Trinity's Keegan Waggoner, Environmental Scientist) as "garbage and septic (very intense) and sulfur (mild intensity)." This, presumably, is because landfill leachate (which is an established source of intense malodors) is coming into direct contact with ambient air, as opposed to being contained within what should be essentially entirely closed systems.

Second, odors in ambient air near the "hot wells" were characterized as "garbage (very intense), burnt (mild intensity)." The elevated temperatures in these wells are due to subsurface exothermic reactions.

Third, and possibly related to these subsurface reactions, one or more "chimneys" have opened up at the Bristol landfill; and odors in ambient air near one of these were characterized as "garbage (moderate intensity), burnt (very intense), sulfur (moderate intensity)."

Fourth, ambient air at the compost area was characterized as "earthy/musty, mild intensity."

Fifth, ambient air at a location on the formerly closed landfill, where landfill mining operations had been occurring, was characterized as having "no noticeable odor."

Taken together, then, it appears that:

i. Leachate mismanagement is a significant source of malodors.
ii. The exothermic subsurface reactions are also sources of odors.
iii. The composting area did not appear to be significant source of malodors at the time of Trinity's sampling program, although a compost-like smell has been reported on at least one occasion.
iv. Mining of old waste at the formerly closed portion of the landfill is not currently a source of odors. Mining of MSW landfills typically generates malodors, but, lacking historic data, we cannot determine whether this was or was not the case at the Bristol landfill.

HEALTH RISK ASSESSMENT: METHOD AND MATERIALS

Turning now to the question of whether airborne emissions from the Bristol VA landfill likely cause irreversible harm to people's health (over and above harming their quality of life), we begin by noting that the usual method for assessing the health effects of facilities that emit potentially harmful chemical, physical, or biological materials is to:

i. measure both the locations and the emission rates of such materials at the emission-sources,

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ii. perform air dispersion modeling to estimate concentrations in ambient air nearby, and then,

iii. translate these estimated airborne concentrations into estimated risks to public health (often at specific locations, such as people's homes, schools, parks, etc.).

In the case at hand, however, we have some rather limited information as to precisely *where* on the landfill various gases and vapors are being emitted; but no information as to the *rates* at which such emissions are occurring.

To complicate matters further, the landfill is deep within an old quarry, so its current surface is well below grade; and current air dispersion models (other than research models) cannot hope to model such a situation with any reasonable accuracy. Moreover, the wind patterns in the area include a large fraction of calm spells, during which current air dispersion models perform poorly regardless of topography.

In view of the impracticality and likely inaccuracy of available air dispersion models, we instead used the available measurements of air quality from samples taken by (i) contractors for Bristol, VA, (ii) Virginia DEQ, and (iii) contractors for U.S. EPA Region III — off the landfill site and in local neighborhoods — augmented with measurements taken by Trinity Consultants Inc., on behalf of the City of Bristol, TN, near the surface of the landfill itself (as noted above); and we combine these data, as explained below, in order to compare estimated ambient air concentrations with health-based guidelines for acceptable air-quality. Simply put, if estimated concentrations in people's neighborhoods are smaller than health-based guidelines, then ambient air, although odorous, is not expected to harm public health. By the same token, if estimated concentrations in people's neighborhoods are instead substantially larger than health-based guidelines, then ambient air may well pose a significant risk to public health.

As shown below, the available measurements, while limited and otherwise imperfect, indicate that, *with one possible exception,* potentially hazardous chemicals are not present at concentrations that may pose significant risk of long term impacts on people's health.

Airborne concentrations of one pollutant — benzene — do skew higher than those typically found in ambient air in the U.S.; but, based on data to date, not so extremely high as to pose significant risks of developing irreversibly adverse effects unless these elevated concentrations were to persist for many years to come. That is to say that although, in decades past, many years or decades of occupational exposure to very high concentrations of airborne benzene caused harm to industrial workers' bone marrows, and hence put these workers at increased risk of developing leukemia, the concentrations of benzene at issue here, although higher than "normal" for *environmental* (that is, nonoccupational, outdoor) exposures, are hundreds of times smaller than the concentrations that are known or reasonably expected to harm people's bone marrows (or other internal tissues or organs).

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At present, the available measurements in Bristol, Tennessee all show ambient air concentrations that are, at most, about 15 times higher the current the current long-term average "normal" background levels (and below any health-based benchmark — see below). To be conservative (that is, to err on the side of public health), for our preliminary assessment, we make some "worst-case" assumptions as to how much benzene could be in ambient air in Bristol, Virginia, and so assume that these could be about 7 times higher still in the short-term (up to 24 hours). These assumptions are based on the measurements on the landfill, and on one measurement at one site in Bristol, VA. This site is near the landfill, but is also near fueling operations and motor vehicle traffic, complicating any reliable apportionment of benzene-sources. Additional data are expected, and may help refine or otherwise elucidate this issue.

Importantly, in and around the Bristol landfill, benzene in ambient air apparently comes primarily from a gasoline (or similar fuel) leak somewhere that *enters* the quarry in groundwater, rather than from the MSW contents of the landfill. Data from "gradient water" (which is primarily groundwater that enters the quarry) at the landfill indicate that this benzene-contaminated plume first entered the quarry about five years ago, and is now also contaminating the leachate. This is apparent from the graph shown below.

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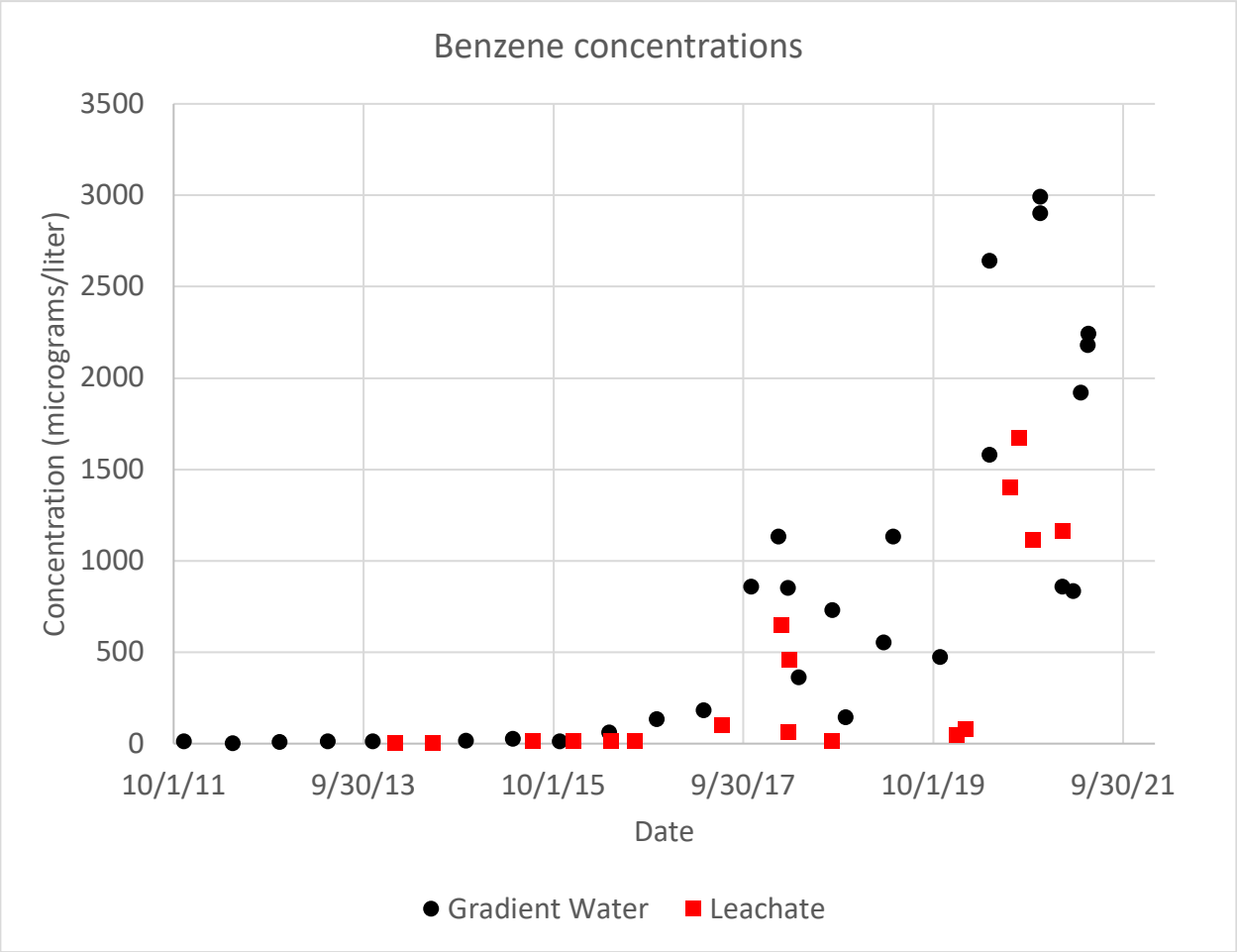

The concentrations of *other* volatile organic compounds are not elevated (except possibly for a simple aldehyde, acrolein, about which more below), and not indicative of hazardous impacts from landfill gas emissions.

In the following sections, we discuss the measurements available and relied on in this assessment, and document the bases of our conclusions.

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AVAILABLE MEASUREMENTS

TO-15 measurements

We rely primarily on measurements made using U.S. EPA method TO-15 (where "TO" stands for "toxic organics"), which is the EPA standard method for measurement of volatile Hazardous Air Pollutants (HAPs — see https://www.epa.gov/haps). In this method, a clean, evacuated, stainless steel canister is allowed to fill to a certain extent with ambient air by opening a valve, the valve is then closed, and the canister is shipped to a laboratory where the entrained air is analyzed.

Different laboratories typically will analyze TO-15 samples for somewhat different sets of volatile HAPs, although those HAPs that are typically found in ambient air are common to all laboratories, and the actual set of analytes evaluated may be modified according to request (and may include analytes that are not designated as HAPs, but are otherwise of interest). This variation is seen for the following three sets of samples.

The method TO-15 ambient air sample measurements[4] available as of December 7, 2021 were as follows:

Bristol, VA samples analyzed by Pace Analytical Services, LLC.

Pace Lab ID	Location	Date of sample
92515956001	2284 Shakesville Rd	01/10/21 20:58
92515956002	523 Maryland Ave/Poplar St	01/10/21 21:15
92529286001	March Comp	03/20/21 09:55
92535070001	First Southwest 6 Arc	04/21/21 13:49
92540483001	24 hrs Sample	05/20/21 09:50
92546378001	24 Hour Sample	06/22/21 10:21

The first two of these were apparently "grab samples" (that is, the valve had been adjusted so that the canisters were rapidly filled with air), while the last four were labeled as 24-hour samples (the valve had been adjusted to allow air to gradually enter the cylinder over approximately 24 hours). The locations of all but the last of these samples is clear from a map available on the Bristol, VA web site (https://bristolva.org/DocumentCenter/View/3274/5-T0-15-Samples)[5], with the first approximately 250 meters N of the north end of the active landfill,

[4] There are further air sample measurements taken in manholes above leachate or gradient water, and one taken of the gases issuing forth from the "chimney" at the SE wall of the landfill. None of these is *directly* useable for evaluation of public health risks, although the last is used indirectly, below, for evaluation of carbon monoxide.

[5] The dates on the map are one day after those given in the table above, which correspond to the times listed on Pace Analytical records (available in https://bristolva.org/DocumentCenter/View/3364/Communication-to-Citizens-82321), and there are minor differences in the addresses.

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the second about 2 km SW of the landfill in a neighborhood where complaints about odors have been made, and the next three about 160 to 170 meters W of the SW corner of the landfill. We do not know where the last "24 Hour Sample" was obtained. We have assumed that these six samples are reasonably reflective of ambient air in neighborhoods near the landfill. We realize, of course, that they are snapshots in place and time.

VA DEQ samples analyzed by VA Division of Consolidated Laboratory Services

Canister ID	Location	Date of sample
526	Shakesville Tabernacle Missionary Baptist Church Parking Lot	12/28/20 22:26
S148	Near 2125 Shakesville Rd. And Near Highlands Juvenile Detention Center	2/28/20 20:52
S230	Intersection Of Booher Rd. And Willow Oak Court	12/28/20 22:01
B061521 S215	1 — Near 450 Booher Rd, Bristol, TN	6/15/21 1:00
B061521 S158	1 — Near 450 Booher Rd, Bristol, TN	6/15/21 20:25
B061821 S213	1 — Near 450 Booher Rd, Bristol, TN	6/18/21 21:00
B062721 524	1 — Near 450 Booher Rd, Bristol, TN	6/27/21 21:45
B071621 408	1 — Near 450 Booher Rd, Bristol, TN	7/16/21 23:40
B062021 521	2 — Int. Booher Rd/King College Rd,Bristol, TN	6/20/21 20:00
B062521 S172	2 — Int. Booher Rd/King College Rd,Bristol, TN	6/25/21 21:15
B062921 S150	2 — Int. Booher Rd/King College Rd,Bristol, TN	6/29/21 18:45
B061821 533	3 — 1909 Kings Mill Pike, Bristol, VA	6/18/21 22:00
B070821 402	4 — 856 E Mary St. (at Delaney St.), Bristol, TN	7/8/21 17:35
B071521 401	4 — 856 E Mary St. (at Delaney St.), Bristol, TN	7/15/21 21:15
B070821 S107	5 — Near 450 Booher Rd, Bristol, TN	7/8/21 20:30
B070621 542	6 — Near 19 Milburn Dr, Bristol, VA	7/6/21 21:20
B071421 405	6 — Near 19 Milburn Dr, Bristol, VA	7/14/21 18:45

The first three of these samples were apparently grab samples.[6] The subsequent samples were obtained by VA DEQ during the June/July 2021 sampling episode by U.S. EPA's contractor Tetra Tech, and were collected over periods ranging from 8 to 30 hours (Tetra Tech, October 2021).

[6] Data available in https://www.bristolva.org/DocumentCenter/View/3074/Air-Sample-Reports-Combined-122820-.

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Trinity Consultants Inc. samples analyzed by Enthalpy (Trinity Consultants Inc., 2021)

Canister ID	Location	Date of sample
Summa-1 R5091	Leachate Tank	11/16/21
Summa-2 90763	Existing Landfill (498)	11/16/21
Summa-3 0799	Compost	11/16/21
Summa-4 1734	Hot Wells (Active)	11/16/21
Summa-5	Chimney	11/16/21

These samples were taken near the Leachate Tank, on the existing previous landfill (#498), between the compost area and the runoff pond for the compost area, between the "hot wells" on the active landfill (#588), and adjacent to the chimney area on the SE wall of the active landfill (#588). All samples were obtained at a height of about two feet above ground level, for a period of about one hour. They will be referred to as "on the landfill" in what follows, since they are either on or in close proximity to the active landfill (#588).

Other samples

In addition to the samples analyzed by method TO-15, Trinity Consultants Inc. also sampled for:

1. Formaldehyde using U.S. EPA Method 11A at the same locations listed in the table above, with a sampling time of about 30 minutes in each case. The results from these samples are included below.
2. Various sulfur containing (odorous) chemicals (hydrogen sulfide, carbonyl sulfide, methyl mercaptan, dimethyl sulfide, carbon disulfide, and dimethyl disulfide) using U.S. EPA Method 15/16 at the locations listed above. These compounds were not detected at any of the five locations, although the lower limits of detection were not very sensitive, and we understand that U.S. EPA's October sampling event did detect at least hydrogen sulfide in at least some neighborhood samples. Again, once we have access to these data, we will update our assessment.
3. Polycyclic aromatic hydrocarbons (PAHs) using U.S. EPA Method 11A, with a sample collection time of three hours, at the "hot wells" location. PAHs are products of incomplete combustion and/or pyrolysis, and we expected to find elevated concentrations of one or more of these compounds if the "hot wells" are indeed reflective of combustion and/or pyrolysis in the landfill. No visible smoke was apparent, so Trinity could not observe directly whether parts of the landfill are currently burning or even smoldering.

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RESULTS

The following table shows the higher of either (i) the maximum ambient air concentrations observed in any neighborhood location (*i.e.* among the Bristol, VA and VA DEQ samples listed above); or (ii) one-third of the maximum concentrations observed on the landfill *per se* (*i.e.* among the Trinity Consultants samples listed above), as our very conservative *estimate* of 1-hour maximum concentrations that might be in any neighborhood location, for a subset of 15 (chosen as described below) of the chemicals analyzed for which at least one sample contained a detectable value.

These (either measured or estimated) maximum concentrations are then compared with available benchmarks of "no significant risk of health effects," which, in this case, are Virginia SAACs, U.S. EPA RfCs, and ATSDR MRLs (all defined below) — in the manner described below.

Please note that another 88 chemicals were sought in the laboratory analyses of one or more samples, but 37 were not detected in any samples (and so not tabulated here); and yet another 37 chemicals *were* detected in one or more samples, but only at such small concentrations, relative to their respective health-based guidelines, that they are omitted from our table (in other words, they are present in only trace amounts), and 14 were detected but have no health-based benchmarks and are also omitted.

We chose one-third of the maximum concentration on the landfill to take account of some dilution when air blows from the landfill into neighborhoods; and this is a conservative assumption (intended to err on the side of public health), since, except under extremely calm conditions, offsite concentrations will be smaller than one-third of onsite concentrations. (Again, we do not have the data one would need to be any more precise; so this conservative assumption seems to us to be appropriate).

The health-based benchmarks are as follows.

A Virginia SAAC (Significant Ambient Air Concentration) is a "concentration of a toxic pollutant in the ambient air that, if exceeded, may have an adverse effect to human health" (https://www.deq.virginia.gov/permits-regulations/permits/air). SAACs are defined by 9VAC5-60-330 (https://law.lis.virginia.gov/admincode/title9/agency5/chapter60/section330/. A list is available at https://www.deq.virginia.gov/home/showpublisheddocument/5546/637516769161600000). Both hourly and annual SAACs are defined, corresponding to exposures over those time-periods.

U.S. EPA Reference Concentrations (https://www.epa.gov/risk/regional-screening-levels-rsls-users-guide) are "an estimate (with uncertainty spanning perhaps an order of magnitude) of a continuous inhalation exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime." The (chronic)

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RfC corresponds to “continuous or near continuous inhalation exposures that occur for 7 years or more,” while the (subchronic) SRfC is “generally used for exposures that are between 2 weeks and 7 years.” A list is available at https://www.epa.gov/risk/regional-screening-levels-rsls-generic-tables.

An ATSDR Minimal Risk Level (MRL) (https://www.atsdr.cdc.gov/mrls/index.html) is “an estimate of the daily human exposure to a hazardous substance that is likely to be without appreciable risk of adverse non-cancer health effects over a specified duration of exposure.” Up to three MRLs may be defined for any substance — acute, intermediate, and chronic (abbreviated here to aMRL, iMRL, and cMRL respectively) corresponding to exposure periods from less than 2 weeks, 2 weeks to 7 yrs, and more than 7 years respectively. (Please note that ATSDR does not generate MRLs to account for carcinogenic effects, although the Virginia SAACs do account for risks of both cancer and all other noncancer effects).

Last, the National Ambient Air Quality Standards (https://www.epa.gov/criteria-air-pollutants/naaqs-table) “provide public health protection, including protecting the health of "sensitive" populations such as asthmatics, children, and the elderly.” NAAQS for each material (carbon monoxide, lead, nitrogen dioxide, ozone, particulate pollution, and sulfur dioxide) are set for various averaging periods. For carbon monoxide, the only NAAQS pollutant considered here, there are 1 hour and 8 hour standards of 35 ppm and 9 ppm respectively.

At present, we can estimate short-term (nominally 1-hr) concentrations of chemicals from the landfill; although some of the measurements described above correspond to up to 30-hours of sampling times.[7] We then compare each estimated 1-hour maximum concentration with its respective, health-based, hourly SAAC and aMRL. If these estimated 1-hour maxima are smaller than these respective health-based guidelines, then no short-term health effects are expected. In other words, it is expected that these maximum concentrations would be harmless over the short term.

For longer exposures, we estimate an average concentration for periods exceeding 2 weeks up to 7 years at one-third of the 1-hour maximum, and compare with the SRfC and the iMRL; while for more than 7 years we estimate average exposure, again, conservatively, as one-tenth of the 1-hour maximum; and, again, if these estimates are smaller than the respective RfCs and cMRLs, it is expected that these maximum concentrations would be harmless.

The table lists the 15 chemicals with the highest ratios of estimated concentrations to health-based comparison values — that is, the 15 chemicals with estimated airborne concentrations that are at least one one-hundredth (0.01) of any of their respective health-based benchmark values.

[7] From extended sources such as this landfill, maximum concentrations over one hour and over as long as 30 hours are likely to be similar (U.S. EPA, 2021).

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All other analytes that are not shown in this table were either (i) not detected in any samples (this was the case for 21 of the Method TO-15 chemicals, all six of the Method 15/16 sulfur-containing chemicals,[8] and 11 of the 21 PAH measured), or (ii) detected only at trace concentrations, less than 0.01 of their respective benchmark value (this was the case for 36 Method TO-15 chemicals and one PAH), or (iii) had no benchmark values, because they are not considered by either Virginia DEQ, U.S. EPA, or ATSDR to be of toxicologic concern (the case for six Method TO-15 chemicals and nine PAH).[9]

Several findings are of note.

First, only the first two chemicals listed in the table — namely, acrolein and benzene — are estimated to be present at concentrations that exceed any of the health-based benchmark values.

The first of these, acrolein, is an aldehyde that is ubiquitous in both ambient air and indoor air, with typically higher levels indoors (ATSDR, 2007). Acrolein is difficult to measure accurately in ambient air; and the data available to us may thus be inaccurate. Regardless, the landfill does not appear to be a significant source of acrolein, however, since higher levels were measured in various neighborhoods rather than in air directly above the landfill itself.

Typical sources of acrolein in air include engine exhaust and other combustion and pyrolysis sources (including gas-stoves, smoke, and highly heated cooking oils).

Trace amounts of acrolein *are* expected to be present in emissions from combustion of landfill gas (whether in flares or from engines), but are unlikely to constitute a sizable fraction of the measured and/or estimated concentrations in neighborhood air (let alone in indoor air in people's homes).

The relatively narrow range of measured values is shown in the graph below (where lines to the left of points indicate non-detects, with a detection limit equal to the point at the right end of the line). This relatively narrow range is consistent with acrolein sources being diffuse, and primarily reflective of automobile and other engine exhausts, both locally and regionally.

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[8] For all the non-detected compounds with health-based benchmarks except hydrogen sulfide, the detection limits were low enough to demonstrate that no sample exceeded any of the health-based benchmarks. For hydrogen sulfide, one benchmark might have been exceeded, but the Tetra-Tech real-time sampling for U.S. EPA in June/July 2021 off the landfill and with considerably lower detection limits showed only intermittent detections at up to 11 ppbV (parts per billion by volume). Taking account of the relevant averaging times, no health-based benchmark was exceeded.

[9] Naphthalene was detected using both Method TO-15 and in the PAH sample; carbon disulfide was detected using Method TO-15 but not using Method 15/16; and *o*-xylene and *m*&*p*-xylenes were separately analyzed (in Method TO-15 samples) but are combined to total xylenes in the table.

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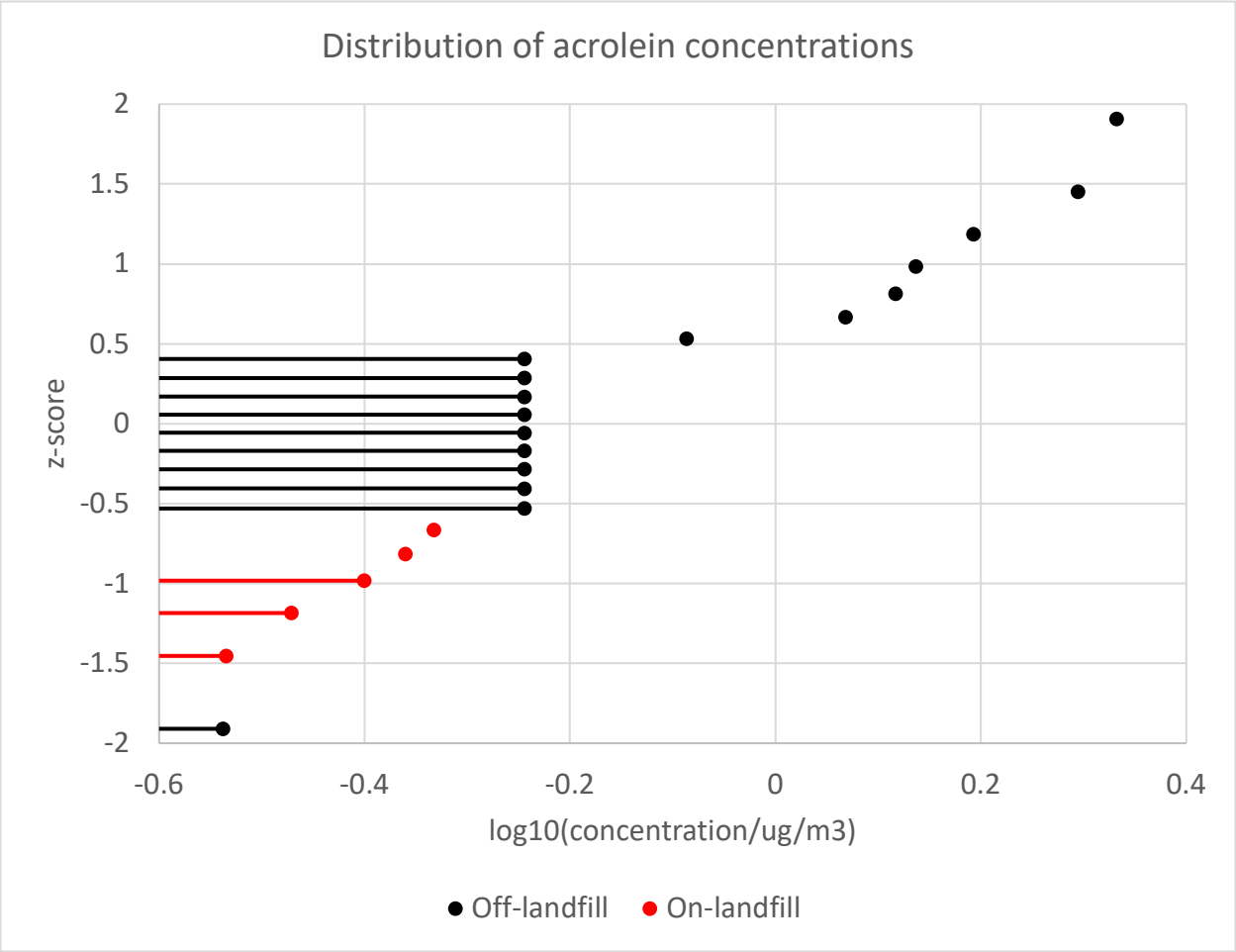
Because, as noted above, measuring acrolein at airborne concentrations this small is technically challenging, and because the guidelines for acrolein in ambient air have been designed, intentionally, to provide a large margin of safety, we do not believe that actual concentrations of acrolein in outdoor air in Bristol, Tennessee, nor in Bristol, Virginia, are unsafe.



The situation with regard to benzene is more complex.

Although benzene concentrations in ambient air are typically also due to engine exhaust and other combustion processes, the available data suggest that the benzene-emissions from landfill sources *per se* are likely to dominate, and to account for most of the substantially elevated concentrations relative to ambient air over otherwise similar cities in the U.S. (which typically average about 1.5 micrograms per cubic meter (µg/m^3) or less).

This situation is reflected in the quite broad range of measured concentrations of benzene in ambient air in all available samples, as shown in the graph below. Note the relatively high

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concentrations of benzene in ambient air samples on the landfill *per se* (at the "hot wells" and the "chimney") and at the "leachate tank": these are shown as the red dots on the upper right — whereas the two other onsite locations (also shown as red dots, but toward the bottom left) with lower concentrations at the "existing landfill (498)" and near the "compost" area, some distance from the active landfill.

In other words, there are benzene sources near the "hot wells", "chimney," and "leachate tank" sample locations, whereas locations away from the active landfill (on the "existing landfill (498)" and near the "compost" area) do not seem to be near significant sources.

Please note that although both benzene and malodors are emanating from the same landfill-sources, this does not mean that benzene is itself a malodor. As it happens, benzene at these airborne concentrations cannot be detected by smell. Benzene happens to smell somewhat sweet, but, again, at the ambient air concentrations at issue, it does not smell at all.

As noted above, benzene being emitted at the landfill appears to emanate not primarily from the landfilled MSW, but instead from intrusion of benzene in groundwater that is leaking into the quarry from an offsite plume, the source of which is unknown, at least to us.

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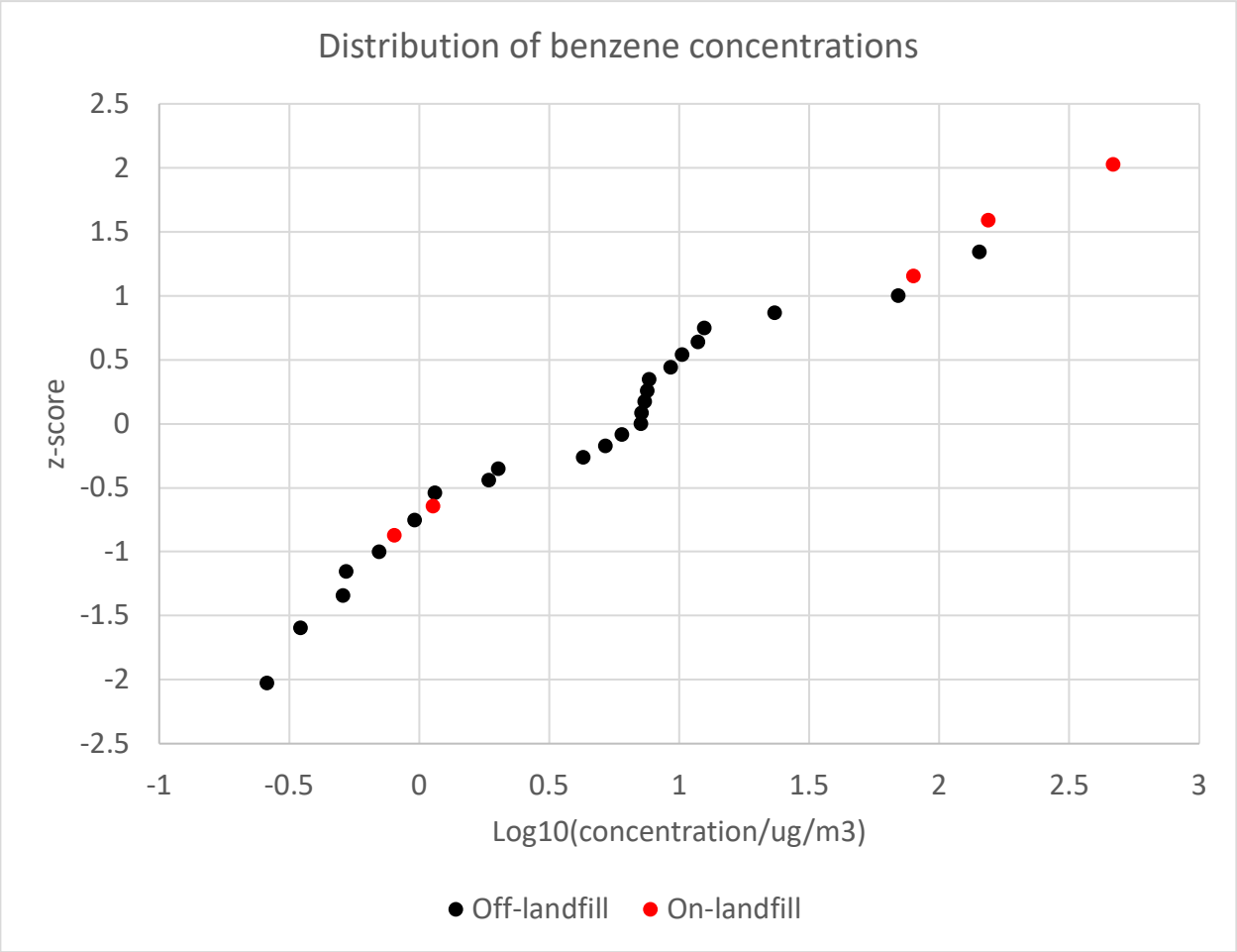

The locations of these ambient air samples are shown in the next figure, below. All concentrations of benzene are in units of micrograms per cubic meter (in $\mu g/m^3$).

Note that, as expected, the highest concentrations of benzene are found at the landfill *per se*, and at locations in Virginia quite near the landfill. Lower, but still elevated concentrations of benzene were detected in more highly populated areas in Bristol, TN, as shown below.

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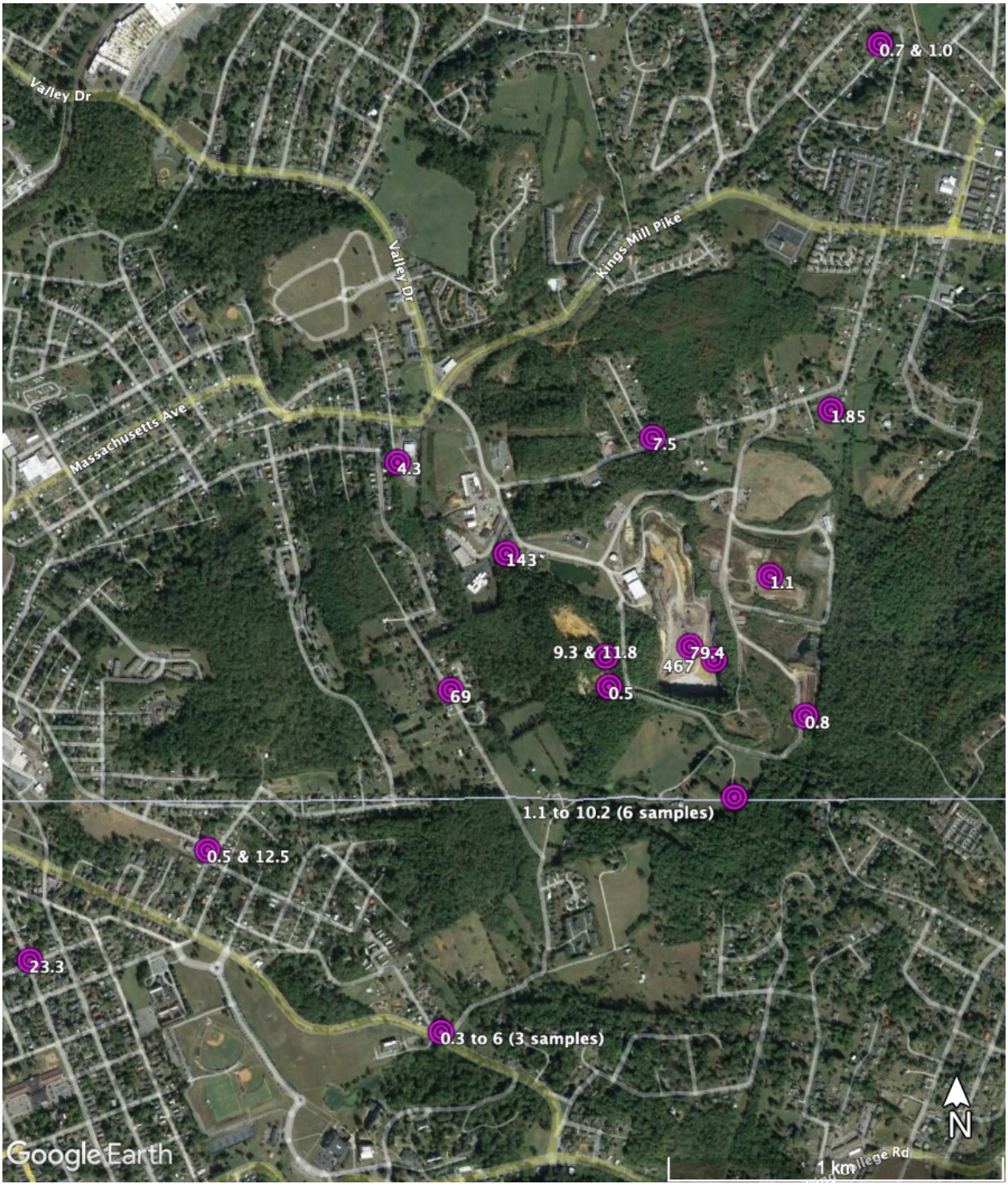

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Second, turning now to whether benzene (or any other air pollutant) is or is not expected to harm public health, please note that the three sets of ambient air benchmarks — that is, the SAACs established by the Virginia DEQ, the RFCs established by the U.S. EPA, and the MRLs established by the ATSDR — differ in their numerical values, even as each such benchmark is health-based.

This is not unusual, since establishing these benchmarks is a multi-step process, involving the translation of results from various toxicologic and/or epidemiologic studies by use of various safety factors and other judgments, both scientific and policy-based, in order to protect public health with an adequate margin of safety.

In the case at hand, notice that the VA SAACs tend to be less stringent than the benchmark values choses by U.S. EPA and ATSDR. Partly, this is because SAACs are used, as a practical matter, to set permit limits for various sources in Virginia; whereas the EPA and ATSDR values are not put to such use (and ATSDR even emphasizes that "**[i]t is important to note that MRLs are not intended to define clean up or action levels for ATSDR or other Agencies"** see https://www.atsdr.cdc.gov/mrls/index.html). Note also that Tennessee has no SAAC-equivalents for these airborne chemicals, although, of course, Tennessee enforces National Ambient Air Quality Standards (NAAQS) and also has two State Ambient Air Quality Standards (SAAQS) for hydrogen fluoride and hydrogen chloride.

Third, the Method 13A PAH measurement was taken at a location between the "hot wells" on the landfill, where, if the subsurface reaction is due to combustion and/or pyrolysis, any products of incomplete combustion would be expected to have the highest concentration. In fact, though, only small concentrations of lower-molecular-weight PAHs were found (C_{16} and lower): naphthalene (at a concentration well within health-based limits) and nine others for which relevant health-based limits have not been established. Other than naphthalene, the only PAH with a relevant health-based benchmark is benzo(a)pyrene, and it was not detected (and the limit of detection corresponds to a negligible fraction of the health-based benchmark).[10]

Fourth, recall that our estimates of air quality in neighborhoods near the landfill are just that: estimates. We believe that our estimates are conservative, intentionally made to err on the side of public health, in the absence of additional data. As noted above, we expect to update our assessment once data from U.S. EPA's contractor's October 2021 sampling and analysis are available to us.

Finally, for carbon monoxide there is currently only one available ambient air measurement of sufficient sensitivity — in the June/July 2021 sampling campaign, EPA contractors monitored

[10] This is consistent with Kret and colleagues' (2018) measurements of ambient air at a "subsurface smoldering landfill," where PAHs, dioxins, and furans, were detected in upwind and downwind samples, and were all below health screening values.

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carbon monoxide at location #5 (with a 1 part per million [ppm] detection limit) and saw just one short term peak of 183 ppm, likely due to operation of motorized vehicle or equipment near the sampler. Since this measurement is not reflective of landfill emissions, we instead make a rough estimate based on the ratio of carbon monoxide to benzene in gas that was issuing directly from the "chimney" on the SE wall of the active landfill. A Method TO-15 sample[11] of this gas contained benzene at 141,000 $\mu g/m^3$, while another sample[12] (unfortunately taken at a different time and analyzed by a different method, U.S. EPA Method 3C) measured 300 ppm of carbon monoxide. The highest estimated 1 hour concentration of benzene off the landfill is 156 $\mu g/m^3$ (see the table). Applying the ratio of benzene concentrations to the carbon monoxide measurement gives an estimated highest 1 hour concentration of carbon monoxide off the landfill of 0.33 ppm, which is well within the NAAQS for carbon monoxide. In other words, carbon monoxide emissions from the landfill are not expected to harm health.

CONCLUSIONS

Measured and estimated concentrations of volatile organic compounds in several samples of ambient air near (and on) the Bristol VA landfill are elevated in benzene, but are otherwise typical of ambient air in similar small cities in the U.S.

Our conservatively estimated benzene concentrations in some neighborhoods close to the landfill are within health-based benchmarks established by the Virginia DEQ and U.S. EPA, but are indeed elevated relative to typical ambient air in small U.S. cities. Our conservative estimates are also *somewhat* higher than guidelines established by ATSDR, although please note again that we do not have a complete dataset yet, and will re-evaluate this issue once U.S. EPA's October 2021 data become available.

For acrolein, our conservatively estimated concentration is within the health-based benchmarks established by Virginia DEQ, but higher than those of U.S. EPA and ATSDR. However, the landfill does not appear to be a significant source of this acrolein; and in any event, again, additional data, from ambient air samples gathered this past October, will allow us to update and further refine this aspect of our assessment. As noted above, we believe that acrolein concentrations in ambient air are not in fact harmful.

Overall, then, our findings are as follows.

The landfill's offensive odors can harm people's (and other animals') sense of well-being, can harm their quality of life, and can induce symptoms such as headaches and nausea.

[11] This sample is included in those available in the document linked in footnote 5, labeled "South East Wall"

[12] This sample, labeled "South East Wall" was taken 5/6/2021 and analyzed by Enthalpy Analytical. The lab report is in a file "SE Chimney -5-6-21 – EPA 3C.pdf" among those obtained from VA DEQ.

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Odors aside, it does not appear that potentially hazardous air pollutants are present at sufficient concentrations in Bristol, TN neighborhood air to constitute health-hazards; although the measured concentrations of benzene do range up to fifteen times higher than typical long-term averages for small cities in the U.S. In Bristol, VA nearer to the landfill, the measured concentrations (which are all short-term) may be up to seven times higher still. We understand that U.S. EPA has gathered additional data.

Also, emissions from the "hot wells" area are quite low in potentially hazardous PAHs, so that the underground exothermic reactions, whether reflective of combustion, pyrolysis, and/or other chemical reactions, are not contributing significant amounts of pollutants (other than benzene) to ambient air even on the landfill *per se*, let alone farther afield. Emissions from these subsurface reactions are contributing malodors, but, again, these malodors themselves do not constitute hazardous conditions, even though they do harm people's quality of life.

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		VA SAAC comparison		U.S. EPA RfC comparison		ATSDR MRL comparison		
Chemical	**Max 1-hr. conc. (μg/m³)**	**Ratio to hourly VA SAAC**	**Ratio to annual VA SAAC**	**Ratio to SRfC**	**Ratio to RfC**	**Ratio to aMRL**	**Ratio to iMRL**	**Ratio to cMRL**
Acrolein	2.15	0.12	0.47	7.8	11	0.31	7.7	
Benzene	156	0.097	0.24	0.65	0.52	5.3	2.7	1.6
1,1,2-Trichloroethane	0.57	0.00021	0.00052	0.017	0.29	0.0034	0.017	
Trichloroethene	1.27	0.000047	0.00024	0.2	0.064		0.19	0.058
Naphthalene	4.27	0.0022	0.0041		0.14			0.11
Formaldehyde	2.05	0.033	0.085	0.019	0.021	0.041	0.018	0.021
1,2-Dibromoethane (EDB)	0.48	0.019	0.069	0.08	0.0053			
1,2,4-Trichlorobenzene	1.04	0.0011		0.017	0.052			
1,3-Butadiene	0.768	0.0007	0.0017		0.038			
Acetonitrile	12.1	0.0048	0.009	0.0081	0.02			
Tetrachloroethene	0.71	0.000021	0.0001	0.0058	0.0018	0.017	0.0057	0.0017
Total xylenes	17.4	0.0011	0.002	0.014	0.017	0.002	0.0022	0.0079
1,2-Dichloropropane	0.42	0.000033	0.000061		0.011	0.0045	0.015	
1,2,4-Trimethylbenzene	6.4			0.011	0.011			
Ethyl Acetate	7.06			0.0034	0.01			

Notes: Blank cells indicate the lack of a corresponding benchmark value.
Omits all other measured chemicals for which maximum concentrations are smaller than 0.01 of their respective benchmark values.
Omits chemicals that were always non-detected; otherwise substitutes ½ of the detection limit for non-detects.
On-site measurements were divided by three, to account, conservatively, for dispersion off-site.

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