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Assessing fentanyl and methamphetamine in the air and on surfaces of transit vehicles

Exposure Assessment Results Final Report, September 2023

ENVIRONMENTAL & OCCUPATIONAL HEALTH SCIENCES
SCHOOL OF PUBLIC HEALTH
UNIVERSITY of WASHINGTON

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Contents

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Acknowledgments

This assessment was funded through a contract with Sound Transit. King County Metro, Community Transit, Everett Transit, and TriMet, in addition to Sound Transit, contributed funding toward this assessment. Several UW faculty, staff, and students contributed to this work, either through helping collect data, providing input on methods and analysis, or helping with interpretation and review. These individuals include: Dr. Edmund Seto, Dr. Christopher Simpson, Dr. Marty Cohen, Dr. Michael Yost, Dr. Shar Samy, Lily Monsey, Pranav Srikanth, Greta Gunning, Bridget Ury, Lilian Liu, Shirley Ching-Hsuan Huang.

The findings reported here are those of the authors and do not necessarily reflect the views or positions of Sound Transit or the other agencies who contributed funding to this assessment.

Executive Summary

- UW researchers undertook an exposure assessment for fentanyl and methamphetamine on transit vehicles. Researchers collected air and surface samples for fentanyl and methamphetamine from a total of 11 buses and 19 train cars. Samples were collected over 28 nights between March 27 and June 22, 2023. Agency partners identified routes, runs, and time of day when smoking of these controlled substances would be most likely to occur based on agency-provided data. Air and surface samples were collected at or near the operator, and in other areas throughout the vehicle where smoke would be expected to accumulate.

- UW researchers analyzed the findings from 78 air samples and 102 surface samples collected from the transit vehicles. Of the 78 air samples, 20 (25%) had detectable fentanyl and 100% had detectable methamphetamine. Of the 102 surface samples, 47 (46%) had detectable fentanyl and 100 (98%) had detectable methamphetamine. Detection of fentanyl or methamphetamine by the lab does not mean it poses a health risk to operators or the riding public.

- No enforceable state or federal regulations exist for methamphetamine or fentanyl exposures occurring in a workplace setting. However, related occupational safety and health standards that are not substance-specific could apply to drug smoke, residues, or paraphernalia found in a workplace setting. These may include standards requiring an accident prevention program, hazard communication, personal protective equipment (PPE), and others.

- One of the 78 air samples collected exceeded the Environmental Protection Agency (EPA) occupational exposure guideline for fentanyl in the air (0.1 micrograms fentanyl per cubic meter of air, $\mu g/m^3$). This is the level of fentanyl measured in air that workplaces should strive to stay below in order to ensure worker health and safety, but it is not an enforceable regulation. No similar state or federal occupational guideline exists for airborne methamphetamine.

- Two of the 102 surface samples exceeded the Washington State Department of Health decontamination guideline established for methamphetamine (15 nanograms of methamphetamine per square centimeter, ng/cm^2). This is a health-based standard, therefore cleaning surfaces to be below this level should protect both operator and rider health.

- In general, levels of methamphetamine and fentanyl found on transit vehicles in this exposure assessment are unlikely to cause acute, short-term physical health effects for the riding public who spend less time on transit than the operators. At the levels seen in this study, there is no evidence of acute medical conditions resulting from passive exposure to fentanyl or methamphetamine (such as from touching contaminated surfaces or inhaling secondhand smoke).

- The potential for long-term physical or mental health effects related to low-level, daily secondhand exposure to fentanyl and methamphetamine should also be considered for transit operators, who spend 40+ hours each week on the bus or train. Long-term health effects related to daily secondhand exposure to these substances are not established. In the absence of data relating the amount of these substances found in the air or on surfaces to human health outcomes, protective measures are prudent to keep operators safe. UW researchers recommend using protective measures to reduce exposure to these substances to the lowest level that is reasonably achievable.

- Protective measures may help to reduce exposure to fentanyl and methamphetamine on transit for operators and the riding public. Suggested protective measures include improved ventilation and air filtration, enhanced cleaning practices, and operator training on agency protocols around the use of drugs on vehicles and other related topics. These controls should be evaluated to determine effectiveness. It is also recommended that agencies continue to work with state and county health agencies to address the use of controlled substances on transit. Enhanced cleaning and filtration have additional benefits for public health such as reducing exposure to wildfire smoke and reducing the spread of respiratory illness.

- Observing drug use in a bus or train can be stress-inducing for operators and the riding public, and may increase feelings of stress, anxiety, or job dissatisfaction. For individuals who may be in recovery or have had family or loved ones impacted by drug use, these feelings may be particularly heightened. These mental and psychological impacts should also be acknowledged and considered.

- Results from this exposure assessment could inform ongoing research focused on occupational exposure to secondhand smoke from drug use. This research can help establish best practices for transit agencies in Washington State, the Pacific Northwest, and nationally. Additional research is needed to establish the long- and short-term health effects related to inhaling or touching secondhand fentanyl or methamphetamine.

What this assessment did not do:

- This assessment did not characterize short- or long-term health outcomes associated with secondhand exposure to fentanyl or methamphetamine. This assessment did not collect internal biomarkers of exposure (such as urine or blood) from operators or the riding public to understand how much of what was found in the air or on surfaces entered people's bodies.

- This assessment did not comprehensively characterize every bus or train route across all times of day. While our results reflect actual and feasible exposures for transit operators, results presented here cannot be assumed to be typical for all transit lines, particularly for those on which reported drug use is less frequent.

Project Introduction

Transit operators have observed and reported instances of drug use on their vehicles, raising concerns about secondhand exposure—both to themselves, passengers, and other transit employees. Some operators have reported acute health effects related to perceived secondhand exposure to drug use, smells, or aerosols. Transit operators often spend 8-12 hours in the bus or train they operate and are responsible for passenger safety. Supervisors responding to incidents and vehicle maintenance employees working on or cleaning coaches could also have exposure to drug residue. As such, it is a high priority for both occupational and community health to assess what levels of secondhand exposure to drugs (e.g., fentanyl, methamphetamine) operators may encounter on transit vehicles such as buses and trains. Given this, transit agencies in the Pacific Northwest requested UW researchers undertake an exposure assessment and recommend protective measures transit agencies can take to reduce exposure to secondhand drug residues, with the goal of increasing overall comfort, safety, and well-being for transit employees.

Overview of Fentanyl and Methamphetamine

In this exposure assessment, fentanyl and methamphetamine are the chemical substances of interest. Fentanyl is a synthetic opioid, which has important use clinically. In a clinical setting, it is very commonly used because of its ability to safely and effectively relieve severe or chronic pain and induce sedation. The World Health Organization (WHO) has listed the fentanyl transdermal patch on their Model List of Essential Medications (1). It is the misuse of fentanyl, outside of a clinical setting or without physician supervision, that is associated with overdoses. Fentanyl is also found mixed with other drugs when used illicitly, which can lead to users not knowing they are consuming fentanyl and can make it harder to identify which drug(s) may be causing an overdose. Fentanyl and methamphetamine is a common drug pairing found in Washington state (2). Fentanyl's effects are euphoria, drowsiness, nausea, confusion, sedation, unconsciousness, and problems breathing. A fentanyl overdose occurs when breathing slows or stops. When used illicitly, fentanyl is typically a powder or pill that can be snorted, taken orally as a tablet, spiked onto blotter paper and used sublingually, or smoked. Absorption of fentanyl through the skin is negligible, and touching fentanyl or fentanyl contaminated surfaces is not believed to pose a clinically meaningful health risk (3). Additional information on fentanyl can be found on the National Institute on Drug Abuse website (4).

Methamphetamine is a stimulant chemically similar to amphetamine, which is used in the treatment of attention-deficit hyperactivity disorder (ADHD) or narcolepsy. Like fentanyl, methamphetamine is on the United States Controlled Substances Act List of Schedule II Drugs, indicating that it has both a currently accepted medical use but also a high potential for abuse and dependence (5). When used illicitly, methamphetamine can be consumed by swallowing a pill, snorting a power, injecting a dissolved powder, or smoking the powder.

Methamphetamine's effects can include decreased appetite, increased physical activity or wakefulness, rapid and/or irregular heartbeat, faster breathing. Long-term use can result in dental problems, anxiety, changes in brain structure, memory loss, sleeping problems, hallucinations, violent behavior, and paranoia, amongst other systemic effects. Overdose is also possible from methamphetamine. Additional information on methamphetamine can be found on the National Institute on Drug Abuse Website (6). For this project, researchers primarily focused on exposures due to smoking fentanyl or methamphetamine, which typically involves putting a solid form of the drug on a creased piece of aluminum foil and heating it from below with a lighter, then inhaling the smoke into the lungs using a straw, pipe, or another piece of foil rolled into a tube.

Methods Overview

UW researchers collaborated with local transit agencies to develop and deploy assessment strategies. Researchers used standard occupational hygiene sampling methodologies to quantify fentanyl and methamphetamine in the air and on surfaces.

Overview of air sampling for occupational hygiene exposure assessment

Air monitoring was conducted using SKC AirChek5000 pumps connected to a 25 mm 5-micron (μm) nylon filter in a 3-stage 25mm black polypropylene cassette and calibrated to a flow rate of 2 liters per minute (LPM). Pump calibration was performed before and after each sampling period to determine an average volumetric flow rate. Air samples were submitted to Bureau Veritas (BV), an American Industrial Hygiene Association (AIHA) accredited laboratory (7), located in Lake Zurich, IL who analyzed them for fentanyl and methamphetamine[a] in accordance with the OpiAlert method (8). Laboratory results were then converted to average air concentrations (e.g., micrograms of drug per cubic meter or $\mu g/m^3$) based on the air sample volume collected for comparison to applicable guidelines and standards. Samples were collected for varying amounts of time, depending on agency-specific protocols and varying lengths of transit routes or runs. Laboratory recovery from the filter (e.g., the extracted mass measured by the OpiAlert analytical method) has been shown to decrease for some drug compounds after four hours (240 minutes) of sampling. For fentanyl, BV reported mean recovery ranged from 70% to 80% after four hours depending on the mass of contaminant on the filter. For methamphetamine, BV reported mean recovery ranges from 85% to 99% after four hours, depending on the mass of contaminant on the filter. For periods greater than 240 minutes, sample results could potentially have lower recovery, resulting in a potential underestimate of concentration. Results were not corrected for recovery.

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[a] Air and surface samples collected early in the assessment were analyzed for fentanyl, carfentanil, cis-3-methylfentanyl, methamphetamine, heroin, and oxycodone; subsequent samples were only analyzed for fentanyl and methamphetamine as the other substances were not detected in air or surface samples. A few samples later in the project (*n*=7 air, *n*=6 surface) were analyzed for cocaine; results are not presented here.

Twenty-one of our 78 (27%) air samples were collected for longer than four hours, and none of the air samples were collected for longer than five hours. Sample results reflect the average concentration for the period monitored. If conditions are assumed to be the same for the unmonitored period, sample results can be interpreted as an 8-hour Time Weighted Average (TWA_8). For the purposes of this assessment the sample results are interpreted as a TWA_8 given the frequency of reported drug-use events on the routes and runs targeted for sampling.

In this assessment, UW researchers collected “area samples” and “environmental samples”. Samples taken in a general area, not specific to one individual, are considered **“area samples”**. Samples taken outside of transit vehicles, as background samples in the general community, are referred to as **“environmental samples”**. Samples taken near the operator (either in the operator’s cab on the train, or at the operator’s seat on the bus) are considered area samples for this assessment as the sampling pumps were not worn by the operator. However, these samples can be considered to be representative of operator exposure, given their proximity to operators.

Samples collected in the field were transferred on ice to UW freezers prior to submission to the laboratory. Samples were shipped on dry ice for laboratory analysis. Researchers also collected air blank samples (e.g., field blanks) which were handled and submitted to the laboratory in the same manner as collected samples. These field blanks were collected across different days and agencies as an internal check for contamination when handling sampling materials in the field and were submitted with each batch of samples sent to the lab.

Overview of surface sampling for occupational hygiene exposure assessment

Surface or wipe sampling in occupational hygiene is commonly used to assess the amount of a substance on a surface. To collect these samples, a methanol-wetted swab was rubbed over a 100 cm^2 (10 cm x 10 cm) area. The swab was then stored in a capped glass container to avoid external contamination. Samples collected in the field were stored on ice prior to laboratory submission and shipped on dry ice for laboratory analysis. The mass of fentanyl or methamphetamine collected on the swab was extracted by BV, and analyzed by LC/MS/MS. The mass (in units of µg or ng) was divided by the area which was swabbed (100 cm^2) to calculate a surface density in units of mass per area (e.g., nanograms of drug per square centimeter, ng/cm^2). Surface wipe samples were submitted to BV and analyzed for fentanyl and methamphetamine in accordance with the OpiAlert method (9).

Researchers also collected blank surface samples which were handled and submitted the same as collected surface samples. These field blanks were collected across different days and agencies as an internal check for contamination when handling sampling materials in the field and were submitted with each batch of samples sent to the lab.

Surface samples were collected two different ways during this assessment. Most commonly researchers collected **protocol samples** which were samples collected in a pre-determined and pre-cleaned location on the bus or train. During sampling set-up, pre-identified areas were cleaned (using isopropyl alcohol (IPA), Luminox) and then a swab sample was collected when sampling was concluded. Therefore, findings from protocol samples can be interpreted as: "Did fentanyl and/or methamphetamine deposit on these surfaces during the work shift? If so, how much?" It is important to note that deposition could occur from people smoking, from transfer of these substances from elsewhere in the vehicle, or from transfer from clothes or belongings of the riding public (10,11).

Researchers also collected **accumulated samples.** These were surface samples that were collected without a prior cleaning of the surface. Therefore, the interpretation of these samples is "How much fentanyl and/or methamphetamine has deposited in this location since a previous cleaning?" Researchers typically would not know when the previous cleaning was.

Exposure determinants

In a typical occupational hygiene assessment, exposure determinants are recorded to help interpret findings. In the case of assessing fentanyl and methamphetamine concentrations on transit, knowing the type of drug smoked, amount of drug smoked, how long someone smoked, how many times a smoking event occurred, where on the transit vehicle smoking events occurred, and ventilation parameters at the time of the smoking event would assist in the interpretation of results. Unfortunately, UW researchers were generally not able to capture these exposure determinants since in most instances researchers were not permitted to ride the transit vehicles with equipment, and doing so might have biased results by altering users' behavior. In limited instances researchers were able to use video surveillance footage to understand whether a smoking event occurred, but the general quality of the video made it challenging to rely on as source of data for exposure determinants.

Overview of exposure assessment strategy at each agency

The assessment strategy differed slightly for each agency, informed by agency need and constraints. The goal for sampling at each agency was to collect an air and surface sample near the operator's work area, and elsewhere in the vehicle where smoke would be likely to accumulate. Details of the sampling strategy are summarized in Table 1. In total, samples were collected across 28 nights, from four agencies, and on a total of 11 buses and 19 train cars. Routes, runs, and time of day for sampling were determined through agency input and were targeted based on previous operator and rider reports of drug use, as collected by agencies and provided to UW.

In order to sample on trains (Agency ID 1 and 4), researchers fabricated a Kidex® thermoplastic panel which could be inserted in the window on the operator door. This panel had a hole in which researchers fitted an air sampling cassette and filter that faced out into the passenger area, while hiding the sampling pump inside the operator cab. Another pump and attached cassette/filter was placed in the operator's cab on the back of the seat or nearby to be representative of operator exposure. For bus sampling at Agency 2, the agency fabricated a panel for the back of the bus. Researchers could place sampling pumps behind the fabricated panel, with cassettes/filters facing through holes cut into the panel to sample air in the back of the bus. For Agency 2, a black, plastic magnetic box was also used to hide a sampling pump on the ceiling, concealed behind the reader board toward the rear of the bus. An additional pump was placed on the back of the operator's seat in order to represent operator exposure. For Agency 3, a pump was placed on the back of the operator's seat, and a second pump was concealed in the back of the bus, inside the filter housing[b]. Sampling locations were chosen as to not disrupt operators or passengers, while ensuring equipment safety.

[b] Researchers acknowledge sampling within the ventilation system is not considered ideal occupational hygiene practice due to turbulence and the unequal air velocities of the sample collector and ventilation (e.g., non-isokinetic sampling). However, samples had to be taken under the guidance and allowance of the agencies coordinating the assessment so as not to disrupt operators or passengers, and protect research equipment.

Table 1: Summary of sampling dates and locations of the four agencies participating in this assessment (March-June 2023)

Agency ID	*n* Shifts sampled	Total *n* vehicles sampled	Air sample locations	Surface sample locations	Sample period	Sample time (min)
1_{Train}	9	11 (Siemens 500 series)	• In operator cab • In passenger area	• Back of seats nearest operator cab • Outside door of operator cab	7PM-12AM	59-287
2_{Bus}	15	1 (New Flyer Xcelsior 60' articulated)	• On operator's seat • Mid-bus behind electronic reader board • Rear of bus: streetside • Rear of bus: curbside	• Backs of rear seats: streetside and curbside • In front of rear ceiling vent • Shelf near operator	7PM-11PM	240
3_{Bus}	2	10 (New Flyer Xcelsior 60' articulated)	• On operator's seat • Rear of bus in ceiling vent	• Backs of rear seats: streetside and curbside • In front of rear ceiling vent • Shelf near operator	6PM-11PM	121-267
4_{Train}	2	8 (Siemens 400/500 series)	• In operator cab • In passenger area	• Backs of seats • Behind bench seating in train rear • Outside door of operator cab	7PM-12AM	240-284

n = number

Researchers collected 122 air samples and 144 surface samples, however not all collected samples were submitted for laboratory analysis. This count does not include blank samples submitted for laboratory analysis, or environmental samples. Due to budget constraints, not all collected samples were analyzed. Laboratory analysis priority was given to samples collected during a time when a drug use event was presumed to have occurred based on operator report, surveillance video footage, or researchers finding drug paraphernalia on the buses. Other samples, collected at times where there was no direct evidence of drug use, were also analyzed for comparison. Researchers aimed to get representative samples from both periods when drugs were being used, and periods when drugs were not being used, but this is not definitively known in all instances since researchers were not always aware what happened during the sampling period. The number of samples that were collected and submitted for analysis across the various media are summarized in Table 2.

Table 2: Number of air and surface samples collected and analyzed for this assessment

Agency ID or Sample Type	*n* Air samples collected	*n* Air samples analyzed	*n* Surface samples* collected	*n* Surface samples* analyzed
1_{Train}	32	17	8	8
2_{Bus}	52	36	81	48
3_{Bus}	22	9	29	20
4_{Train}	16	16	26	26
$\text{Environmental}_{Washington}$	9	9	9	9
$\text{Environmental}_{Oregon}$	6	6	5	5
Blanks	20	20	14	14

n = number

**Counts include both protocol surface samples and accumulated surface samples*

Oregon environmental samples include those taken in both Portland and Clackamas; all Washington environmental samples were taken in neighborhoods of Seattle

Environmental sampling methods

In addition to samples on buses and trains, researchers also collected repeat environmental air and surface samples from three locations in Seattle (downtown Seattle; Seattle's UDistrict; and a low-density Seattle neighborhood), downtown Portland, and at a hotel in Clackamas, OR. These samples used the same collection methods as samples collected on buses or trains with the exception of surface wipe sampling, which utilized available horizontal metal surfaces in place of the surfaces found on transit vehicles. The goal of collecting these samples was to assess environmental levels of fentanyl and methamphetamine and see how it compared to levels found on transit vehicles. Locations and information on how these environmental samples were collected are detailed in Table 3.

Table 3: Environmental sampling locations and methods, Seattle, Portland, and Clackamas

Location	**Air Sample** (*n*=3 at each location)	**Surface Sample** (*n*=3 at each location, *n*=2 in Portland Downtown)
Seattle: 2nd & James	Pump left on parked vehicle	Collected on roof of parked vehicle
Seattle: UDistrict Neighborhood	Pump in magnetic box on office building roof	Collected on metal bar next to pump
Seattle: Residential Neighborhood	Pump left on parked vehicle	Collected on roof of parked vehicle
Portland: Downtown*	Pump left on parked vehicle	Collected on roof of parked vehicle
Clackamas: Hotel	Pump left on parked vehicle	(1) Collected on roof of parked vehicle (2) Collected on door of parked vehicle (3) Collected on top of electric box

n = number

**Downtown Portland Air Sample locations include: SW 10th Ave & SW Harvey Milk St, SW Taylor St & SW Broadway, SW 9th Ave & SW Alder St; downtown Portland surface sample locations include: SW Taylor St & SW Broadway and SW 10th Ave & SW Harvey Milk St*

For samples collected on a parked vehicle, a car was driven and parked at a given location for the duration of the sampling period. A sampling pump was hidden in or on the car with an attached filter pointed toward the external environment. Environmental surface samples were collected in the same manner as protocol surface samples, with an area on the vehicle cleaned (often, the roof) during set-up, and a surface sample collected at the end of the sampling period. For the UDistrict environmental samples, a pump was placed in a magnetic box which was attached to a metal barrier on the roof of the UW researcher's office building. The surface sample was collected adjacent to where the pump was attached.

Overview of exposure regulations and guidelines

There are no enforceable state or federal standards regulating airborne concentration or surface deposition of fentanyl and methamphetamine in a workplace setting. However, guidance and other related standards are summarized below, which may be a useful benchmark to compare results to.

Airborne fentanyl

United States EPA has established a guideline 8-hour time weighted average (TWA_8) occupational exposure limit (OEL) to airborne fentanyl (12). This was originally developed for workers in fentanyl production for the pharmaceutical industry. The OEL established by EPA is specific to working populations and is 0.1 µg/m^3. This fentanyl OEL is a health-based guideline, which can be interpreted to mean that keeping average work shift exposures below 0.1 µg/m^3 will protect against chronic health outcomes related to fentanyl for nearly all workers. This OEL should not be considered the threshold between safe and hazardous conditions.

US EPA has also established a 24-hr provisional advisory level (PAL) for airborne fentanyl of 0.0037 µg/m^3 (12). This is a 24-hour time weighted average aimed at protecting the general public, and is not directly comparable to a work shift exposure. The EPA PAL is meant to inform risk-based decision making and to inform risk-based clean up guidance. It must be noted that both the EPA OEL and the EPA PAL are not regulatorily enforceable.

Airborne methamphetamine

No health-based guidelines or regulations exist for methamphetamine in air. In the absence of regulatory guidance, occupational health best practices urge workplaces to follow the precautionary principle and control methamphetamine concentrations to a level as low as reasonably achievable (ALARA).

Fentanyl on surfaces

No health-based guidelines or regulations exist for fentanyl on surfaces. In the absence of regulatory guidance, occupational health best practices urge workplaces to follow the precautionary principle and control fentanyl concentrations to ALARA.

Methamphetamine on surfaces

The Washington State Department of Health has established a health-based standard (RCW 64.44) for the decontamination of methamphetamine contaminated properties, which is 15 ng/cm^2 (13). This value means that any property known to have been contaminated by methamphetamine should be cleaned such that all areas of the property are below 15 ng/cm^2. As this is a health-based standard, keeping surface contamination below 15 ng/cm^2 is protective of health.

The Oregon Health Authority has established a decontamination standard for the clean-up of former properties previously used for the manufacture of methamphetamine (OAR 333-040) (14). The Oregon decontamination standard is 0.5 μg/ft^2 which is equivalent to 0.53 ng/cm^2. This standard is not health-based. This regulation only applies to properties that were previously used in the manufacture of methamphetamine.

Short-term v. long-term chemical exposures

There is an important distinction between short-term and long-term chemical exposures. A short-term exposure refers to an exposure received over a short period of time (typically less than an hour). A high short-term exposure could result in an immediate, often reversible health effect, ranging from minor (e.g., nose or throat irritation, discomfort) to more serious (e.g., passing out, eye damage) based on the concentration of chemical in the environment, and the dose entering the person's body (15).

A chronic or long-term exposure refers to continuous or repeated exposure experienced consistently over a long period of time, such as over a working life. While often these low-level chronic exposures would not be high enough to cause immediate health effects, these consistent low-level exposures could cause subtle biological changes or lead to chronic disease outcomes over long periods of time that are often permanent (15).

For the work presented here, the riding public would typically experience fentanyl and methamphetamine exposures for a short period of time, as these individuals spend only part of their day on trains or buses. However, transit operators could spend 40+ hours on the bus or train weekly, for a working lifetime. Therefore, health impacts that could be related to consistent, chronic, low-level exposures would apply to the transit workers and should also be considered alongside acute impacts they could experience. For chemical hazards, the relationships between lower-level, long-term exposures and chronic health outcomes are often less established in the academic literature.

Results

Air sample results

Results from air sampling are presented in Table 4. Findings are presented by type of vehicle (bus v. train), location in the vehicle, and separately for fentanyl and methamphetamine. For bus samples, any sample not taken at the operator's seat was considered as a "Rear" sample. This would include samples taken in the middle or rear of the bus. All bus air samples were collected on New Flyer Xcelsior 60' articulated buses, and all samples other than the sample connected to the operator's seat were collected behind the articulated section of the bus. All train samples were collected on Siemens 400 or 500 series light rail vehicles. Operator samples represent samples taken inside the operator's cab. Passenger samples represent samples in the passenger area train car.

Table 4: Air sampling results for both fentanyl and methamphetamine, by vehicle type and location[c]

	Fentanyl (EPA OEL: 0.1 µg/m³)					Methamphetamine			
Vehicle/ location	*n* samples	*n* (%) detects*	mean (SD) [µg/m³]	range [µg/m³]	*n* (%) above OEL	*n* samples	*n* (%) detects*	mean (SD) [µg/m³]	range [µg/m³]
Bus									
Operator	14	1 (7%)	0.005	NA	0	14	14 (100%)	0.078 (0.22)	0.003 - 0.86
Rear	31	8 (26%)	0.015 (0.014)	0.002 -0.04	0	31	31 (100%)	0.243 (0.609)	0.01 - 2.32
Train									
Operator	17	6 (35%)	0.026 (0.027)	0.005 - 0.078	0	17	17 (100%)	0.027 (0.016)	0.01 - 0.07
Passenger	16	5 (31%)	0.033 (0.052)	0.005 - 0.14	1 (6%)	16	16 (100%)	0.037 (0.021)	0.01 - 0.09

n = number; NA = Not applicable as there was only one sample (single value listed in mean column); SD = standard deviation

**A mass detected above the laboratory limit of quantification (LOQ) of 1 ng (for both fentanyl and methamphetamine). For a four-hour air sample at 2 L/min, this would equate to a concentration of 0.002 µg/m³.*

[c] The researchers acknowledge that exposure data is often log-transformed due to the right-skewed nature of these data, and their underlying lognormal distribution. However, the authors chose to report mean and standard deviation as summary statistics for these data as opposed to the geometric mean and geometric standard deviation for ease of interpretation, along with the range in order to show the spread of these data (16,17).

Results from air samples show that levels of both fentanyl and methamphetamine tended to be higher in passenger areas of the bus and train (denoted as rear and passenger, respectively). One air sample collected had a value (0.14 μg/m^3) that exceeded the EPA OEL for fentanyl. While methamphetamine was detected in all air samples, fentanyl was detected less frequently, in 20 air samples (26%). Researchers collected 20 air field blanks, all of which were below the limit of quantification for both fentanyl and methamphetamine. As such, air sampling data (Table 4) are not blank-corrected.

Air and surface blank samples

Air and surface blank samples were submitted with each batch of samples. The number of blanks collected and levels of fentanyl and methamphetamine found are summarized in Table 5. No air blanks had detectable fentanyl or methamphetamine. No surface blanks had detectable fentanyl. One of the two surface blanks submitted with Batch 4 detected 2.7 ng of methamphetamine. For this reason, all surface samples from Batch 4 (n=20) were adjusted for the average of the two surface blanks submitted with this batch (1.35 ng). This is reflected in the surface samples presented in Tables 6 and 7.

Table 5: Summary of air and surface blanks submitted with each batch of samples

Batch	*n* Air Blanks	Avg. Air Fent [ng]	Avg. Air Meth [ng]	*n* Surface Blanks	Avg. Surface Fent [ng]	Avg. Surface Meth [ng]
Batch 1	2	ND	ND	1	ND	ND
Batch 2	4	ND	ND	3	ND	ND
Batch 3	5	ND	ND	4	ND	ND
Batch 4	4	ND	ND	2	ND	1.35
Batch 5	5	ND	ND	4	ND	ND

n = number; ND = a mass was not detected above the laboratory limit of quantification (LOQ) of 1 ng (for both fentanyl and methamphetamine).

Protocol surface sample results

Results from the protocol surface samples are summarized in Table 6, stratified by location. For buses, samples taken near the driver were coded as “driver” samples, and samples taken behind the driver but in front of the rear doors were coded as “mid” samples. Samples in the “rear” category were those taken in the back of the bus, behind the rear doors, either on seat backs or windows. For trains, samples taken on the outside of the operator door (above the door handle) were stratified from samples collected elsewhere, including on seat backs, or in the rear of the train. For both buses and trains, measured surface contamination tended to be higher in the rear of the bus (or in the passenger area of the train) though there was evidence of surface contamination throughout the vehicle. No protocol samples exceeded the Washington State health-based methamphetamine decontamination standard; though one sample in the rear of the bus was at about half of this standard (6.86 ng/cm^2). Researchers collected 14 field blanks for surface samples. Protocol and accumulated surface samples submitted in laboratory Batch 4 (n=20 total surface samples) were blank-corrected.

Table 6: Protocol surface sampling results for both fentanyl and methamphetamine, by vehicle type and location

	Fentanyl				Methamphetamine			
Vehicle/ location	*n* samples	*n* (%) detects*	mean (SD) [ng/cm²]	range [ng/cm²]	*n* samples	*n* (%) detects*	mean (SD) [ng/cm²]	range [ng/cm²]
Bus								
Driver	15	6 (40%)	0.047 (0.056)	0.01 - 0.16	15	15 (100%)	0.25 (0.14)	0.063 - 0.57
Mid	12	2 (17%)	NA	0.018, 0.022	12	12 (100%)	1.30 (1.74)	0.141 - 4.58
Rear	36	22 (61%)	0.085 (0.13)	0.011 - 0.47	36	36 (100%)	0.97 (1.22)	0.063 - 6.86
Train								
Outside of Operator Door	9	2 (22%)	NA	0.015, 0.13	9	7 (78%)	0.20 (0.32)	0.035 - 0.93
Passenger Area	17	5 (29%)	0.077 (0.075)	0.014 - 0.17	17	17 (100%)	0.32 (0.44)	0.013 - 1.32

n = number; NA = Not applicable, because there were fewer than 3 samples; SD = standard deviation
**A mass detected above the laboratory limit of quantification (LOQ) of 1 ng (for both fentanyl and methamphetamine). For a 100 cm^2 surface sample, this would equate to a surface loading of 0.01 ng/cm^2.*

Accumulated surface sample results

In total, researchers collected 13 accumulated surface samples. Table 7 outlines the location of these samples, and the surface loading of both fentanyl and methamphetamine found on these samples. Two samples collected were above the health-based Washington State Standard for methamphetamine decontamination of 15 ng/cm^2, both were collected inside the filter housing part of the ventilation system in the rear of the bus—an area that typically would not be able to be touched by the public. For both of these samples, there was no evidence of drug use directly prior to collecting the sample.

Table 7: Summary of accumulated surface samples

Location	Fentanyl [ng/cm^2]	Meth [ng/cm^2]
Inside Vent Bus 1	1.06	53.4
Inside Vent Bus 2	0.846	44.3
Outside Vent Bus 3	0.025	12.6
Outside Vent Bus 4*	ND	5.34
Rear Door Handles Bus 4*	4.27	1.86
Rear of Train 1	0.207	0.86
Middle Seatback Train 1	0.092	0.801
Outside Operator Door Train 1	ND	0.114
Rear of Train 2	0.053	0.923
Middle Seatback Train 2	ND	0.114
Outside Operator Door Train 2	0.117	0.222
Front Seatback Train 3	0.117	0.79
Rear of Train 3	0.728	2.23

**Samples collected due to seeing drug paraphernalia*

ND = Not detected; not detected above the laboratory LOQ of 1 ng (for both fentanyl and methamphetamine). For a 100 cm^2 surface sample this LOQ would equate to a surface loading of 0.01 ng/cm^2.

Environmental sampling results

Air and surface sample results from environmental sampling are presented in Table 8. Across Portland, Clackamas, and Seattle, no air or surface sample was collected where fentanyl was detected above the lab limit of quantification. For the nine air samples collected in Seattle, two (22%) had detectable methamphetamine. For the six air samples collected in Oregon (Portland and Clackamas), two (33%) had detectable methamphetamine (both in Portland). A total of four environmental surface samples had detectable methamphetamine, three collected in Seattle and one collected in Portland. In general, the background levels observed for this limited-scope environmental sampling assessment were lower than the levels of both fentanyl and methamphetamine measured on transit.

Table 8: Summary of environmental air and surface samples collected in Seattle, Portland, and Clackamas

	Air Samples			Surface Samples		
Location	***n***	**Fentanyl concs. [µg/m³]**	**Meth concs. [µg/m³]**	***n***	**Fentanyl values [ng/cm²]**	**Meth values [ng/cm²]**
Seattle: 2nd & James	3	ND	ND, ND, 0.003	3	ND	0.012, 0.014, 0.015
Seattle: UDistrict	3	ND	ND	3	ND	ND
Seattle: Residential	3	ND	ND, ND, 0.006	3	ND	ND
Portland: Downtown*	3	ND	ND, 0.005, 0.005	2	ND	ND, 0.015
Clackamas: Hotel	3	ND	ND	3	ND	ND

ND = Not detected; not detected above the laboratory LOQ of 1 ng (for both fentanyl and methamphetamine). For a four-hour air sample at 2 L/min, this LOQ would equate to a concentration of 0.002 $\mu g/m^3$. For a 100 cm^2 surface sample this LOQ would equate to a surface loading of 0.01 ng/cm^2.

**Downtown Portland Air Sample locations include: SW 10th Ave & SW Harvey Milk St, SW Taylor St & SW Broadway, SW 9th Ave & SW Alder St; downtown Portland surface sample locations include: SW Taylor St & SW Broadway and SW 10th Ave & SW Harvey Milk St*

Table 9 compares the highest levels of environmental (background) methamphetamine measured in air and on surfaces in Seattle, Portland, and Clackamas to the levels of methamphetamine found in buses and trains. No comparison is made for fentanyl since no environmental (background) levels of fentanyl were detected. From Table 9 it can be seen that levels found on buses and trains tended to be higher than environmental samples. A typical air sample collected on a bus or train had three times more methamphetamine than the environmental air samples; a typical surface sample collected on a bus or train had about 20 times more methamphetamine than the environmental surface samples.

Table 9: Comparison of highest environmental air and surface samples (across Seattle, Portland, and Clackamas) to air and surface samples from transit vehicles

Highest Environmental Air Meth: 0.006 µg/m^3	
n (%) transit air samples below environmental:	1 (1.3%)
n (%) more than 10x higher than enviro (>0.06 µg/m^3):	10 (13%)
n (%) more than 100x higher than enviro (>0.6 µg/m^3):	4 (5%)
Median % diff in buses/trains compared to enviro:	311%
Highest Environmental Surface Meth: 0.015 ng/cm^2	
n (%) transit surface samples below environmental:	3 (3%)*
n (%) more than 10x higher than enviro (>0.15 ng/cm^2):	71 (71%)
n (%) more than 100x higher than enviro (>1.5 ng/cm^2):	18 (15%)
Median % diff in buses/trains compared to enviro:	2256%

n = number

**This includes two surface samples which were ND (below laboratory LOQ)*

*Percent difference calculated as: ((transit value – enviro value) / (enviro value)) * 100*

Comparison of results to other studies

While limited, there is existing academic literature that has measured levels of methamphetamine in the air using similar filter-based methods, which can serve as a comparison for results presented in Table 4. That literature is summarized in Table 10, to further contextualize the findings reported here for methamphetamine in air.

Table 10: Reported values of methamphetamine in air in the scientific literature, compared with concentrations in this assessment (in **bold**)

Meth Air Conc. [μg/m³]	Note
5500	During manufacture—post cook
300—1600	At source when smoking
210	In lab 24-h post manufacture
42	During manufacture—cook phase
2.32	**Highest air concentration found in this assessment**
0.53—8.3	Urban residential house 10 years after used for manufacture
0.2—7.3	Indoor air in property seized by police for clandestine manufacture (USA)
0.2—3	Properties suspected to manufacture meth (New Zealand)
0.119—0.709	Various locations at former meth lab (Minnesota)
0.027—0.243	**Range of mean air concentrations found in this assessment**
0.0016—0.30	Rural residential house ~2 years after used for manufacture

Source: Wright J, Symons B, Angell J, Ross KE, Walker S. Current practices underestimate environmental exposures to methamphetamine: inhalation exposures are important. J Expo Sci Environ Epidemiol. 2021 Feb;31(1):45-52. doi: 10.1038/s41370-020-00260-x.(18)

Recommendations and Conclusions

Based on the results presented here, UW researchers have outlined recommended protective measures transit agencies can take in regard to fentanyl and methamphetamine on surfaces and in the air. UW researchers stress that protective measures should be evaluated for effectiveness and done in consultation with all relevant union representatives. UW researchers also recommend engaging local and state public health departments in efforts. Other recommendations include:

- **Upgrade filtration:** Upgrade filtration to a minimum efficiency reporting value (MERV) of 13 on transit vehicles, or to as high of a MERV filter rating as feasible. Filters rated MERV 13 or above are proven to have greater filter efficiency for smoke/combustion products compared to filters with a lower MERV rating (19). Ensure the filters are changed on schedule. This will have the added benefit of also providing increased protection against wildfire smoke and respiratory illnesses.
- **Develop enhanced cleaning protocols:** Consider increased frequency, thinking about areas on transit that may need a “deep cleaning” as well as ensuring solvents are being used that are appropriate for both water soluble (i.e., fentanyl) and water insoluble (i.e., methamphetamine) contaminants. Consider the occupational health and safety needs of the cleaning personnel to safely perform these enhanced cleaning tasks.
- **Continue to train/educate employees about these hazards:** This can include updated or more frequent trainings on topics such as agency protocols operators should follow when they observe a smoking event, real and perceived risks related to secondhand drug exposure, how and when to deploy naloxone (Narcan), and other related topics. Research with police officers and first responders has shown that medically accurate training about fentanyl can increase knowledge in these occupational groups, and correct misconceptions about exposure and risk of overdose (20–22).
- **Consider mental health supports:** Observing drug use at work could feel stressful or unpredictable for transit workers (23). Depending on their personal history with drugs (e.g., they may be in recovery, or have had a family member or loved one impacted by drug use) these feelings could be heightened. Acknowledging the potential mental health impacts of observing drug use on transit and ensuring operators have access to mental health support is recommended.

Limitations and Future Work

This assessment had limitations that must be acknowledged, and will hopefully inform future related work.

- **Determinants of exposure were not directly assessed:** As described in the methods, researchers were not able to comprehensively or consistently document exposure determinants, such as whether or not smoking events definitively occurred when pumps were running. Additionally, when smoking events did occur, researchers did not know exactly what was being smoked and how much was being smoked. This analysis only focused on fentanyl and methamphetamine, and did not assess other drugs that may be used on transit.
- **Health outcomes were not assessed:** Researchers did not assess short-term or long-term physical or mental health impacts potentially associated with fentanyl and methamphetamine exposures, either for operators or the riding public. Understanding the relationship between levels of exposure and health outcomes would be an important direction for future work, and could help to inform evidence-based guidelines or standards around these substances.
- **No internal measures of exposure were assessed:** Researchers did not collect internal measures of exposure (biomarkers of exposure) such as urine or blood, from operators or the riding public. Such measures would allow a greater understanding of how much of an external exposure enters an individual's body, where it can potentially exert toxic effects.
- **Different exposure assessment strategies were used between agencies:** Researchers worked with four agencies on this assessment, and based on agency-specific needs and restrictions, exposure assessments were carried out slightly differently between each agency (see Table 1). In the results, data are presented in a way that allows for combining data from multiple agencies, though often at the expense of specificity (for example, grouping locations as "mid" or "rear" on the bus).
- **This was not an experimental study:** Data for this assessment were collected during actual transit runs. UW researchers and agencies were mindful that the assessment strategy could not disrupt operators or the riding public, and that equipment needed to be secured and concealed. While this allowed for the collection of real-use data, ensuring that the assessment did not disrupt transit users sometimes meant adjusting where or when samples were collected, further leading to differences in exposure assessment strategies between agencies.
- **This is a limited-scope assessment:** While data were collected over 28 nights, from 11 buses, 19 trains, and 4 transit agencies, these data cannot be taken to be representative of all vehicles, routes, or runs, both in the Pacific Northwest and throughout the country.

Resources

If you or your loved-ones have been impacted by fentanyl, methamphetamine, or other drugs, or you would like to learn more about these substances including treatment, recognizing an overdose, or how to prevent an overdose, the following resources may be helpful:

- Learn about recognizing an overdose and using naloxone: https://stopoverdose.org/
- Learn about accessing treatment: https://www.learnabouttreatment.org/
- Understanding and supporting adolescents with an opioid use disorder: https://adai.uw.edu/pubs/pdf/2021AdolescentsOUD.pdf
- Washington State Recovery Healthline: https://www.warecoveryhelpline.org/
- Public Health-Seattle & King County information on drugs laced with fentanyl: https://www.lacedandlethal.com/
- Public Health-Seattle & King County overdose prevention: http://www. kingcounty.gov/overdose
- Multnomah County Public Health overdose prevention: https://www.multco.us/health/staying-healthy/overdose-prevention
- Oregon Health Authority Fentanyl Facts: https://www.oregon.gov/oha/ph/preventionwellness/substanceuse/opioids/pages/fentanylfacts.aspx
- University of Washington Addictions, Drug, & Alcohol Institute information on recovery/treatment: https://adai.uw.edu/information/treatment-help/
- Snohomish County Health Department Heroin and Opioids: https://www.snohd.org/175/Heroin-Opioids
- NIOSH Illicit drug tool-kit for first responders: https://www.cdc.gov/niosh/topics/fentanyl/toolkit.html

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The University of Washington occupies the traditional land of the Coast Salish peoples. Without them, we would not have access to this working, teaching, and learning environment. We honor and acknowledge the original caretakers of this land, who are still here.

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