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Case Studies

Nicotine Fumigation: A Greenhouse Application

Dawn Tharr, Column Editor

Reported by Ann M. Krake

The National Institute for Occupational Safety and Health (NIOSH) received a request from a university's occupational health and safety program manager for a health hazard evaluation (HHE). The request asked NIOSH to assess potential employee exposures to the fumigant nicotine following fumigation and during maintenance and manipulation of greenhouse research plants.

The primary objectives of the NIOSH evaluation were to characterize greenhouse employees' nicotine exposures and to determine if the time period and areas of restricted entry, as well as the pre-entry ventilation procedures, were adequate for preventing excessive nicotine exposures. A secondary objective was to evaluate an alternative method for assessing airborne pesticide concentrations.

Background

The laboratory facility included a greenhouse with eight 900 cubic feet (ft^3) growing sections and a laboratory, which were connected at one end by a hallway with doors that form an airlock. Each greenhouse section was equipped with one 24-inch exhaust fan located opposite the entrance to the section on the outside wall. The greenhouse contained a variety of plants used to study the transmission of viruses by aphid vectors. Nicotine alkaloid (1-methyl-2((3-pyridyl)pyrrolidine) was used in a biweekly rotation, about every six weeks, with two other fumigants, dithio (tetraethyldithiophosphate) and dichlorvos (2,2-dichlorovinyl dimethal phosphate). Fumigations typically took place every other Friday evening at 7 p.m. Other greenhouse pesticides, including aerosols, fogs, and soil-directed applicants, were used on a weekly or daily basis as needed.

The fumigation procedure was designed to adhere to the Environmental Protection Agency's (EPA) Worker Protection Standard (WPS) [40 CFR Parts 156 and 170],[1] and the university's occupational safety and health program. Prior to fumigation, warning signs, which included emergency personnel contact information, fumigation material, and the dates and times the facility would close and be reopened, were posted on every door leading into the greenhouse area. All entry doors were locked, all greenhouse exhaust fans were disabled at the breaker, all window vents were closed, and two trained employees were present at all times during the lighting of the fumigant containers. The employee primarily responsible for fumigation was a certified commercial pesticide applicator. Nitrile rubber gloves, protective eyewear, and a NIOSH-approved half-face respirator (MSA Comfo®) equipped with chemical and particulate (dust/fume/mist) cartridges approved for pesticides (TC-23C-155) were worn during container activation.

The nicotine fumigant (Fulex® Nicotine Fumigator, Fuller System, Incorporated, Woburn, Massachusetts, EPA Registration Number 1327-33) was packaged in a six-ounce can and contained 14 percent nicotine alkaloid and 86 percent inert ingredients, which included plant by-products impregnated with an oxidizer, sodium nitrate. The nicotine fumigant label stipulates that one can vaporizes in approximately 2–3 minutes and will cover up to 10,000 ft^3. Fumigation was started by shaking the can, placing the can on the floor near the middle of each greenhouse section, lighting a sparkler near the handle end with a propane torch, and placing the sparkler slowly into the mixture in the can. The fumigator started at the farthest end of the greenhouse from the exit, igniting each can, and closing each section door behind him. This process took approximately 15 minutes. The greenhouse was then locked for the next 12–13 hours.

All entry doors to the greenhouse remained locked until the next morning when, 12–13 hours following the start of fumigation, a greenhouse employee unlocked them without entering the greenhouse. Another employee, wearing coveralls, reusable waterproof gloves, and rubber boots, spent approximately 15 minutes in the greenhouse hallway to start mechanical ventilation by opening window vents and turning on the exhaust fans at the breaker box. Also during this time, the employee entered each greenhouse section to collect spent fumigant containers, which are sealed in plastic bags and placed in the garbage dumpster. The greenhouse was left to mechanically exhaust (ventilate) for a period of 2–3 hours, after which time the employee returned to water plants, wearing coveralls and rubber boots, but no gloves. The fumigation warning signs remained posted until Sunday or Monday but may be removed when the mechanical exhaust is complete. Entry by other personnel is discouraged until Monday morning; however, the doors remain unlocked and the greenhouse is accessible approximately 12–13 hours after the start of fumigation.

Methods

Air Sampling

Samples for nicotine were collected on XAD-4 tubes and analyzed by NIOSH Method 2551.[2] A sampling rate of 1.0 liters per minute (lpm) was used to

counteract the pressure drop caused by using two tubes in series in some of the sampling trains. A pre-filter, consisting of a 13-millimeter glass-fiber filter (GFF) in a three-piece closed-face cassette, was used in series with the XAD-4 tubes in some of the sampling trains to assess the contribution, if any, of particulate-bound nicotine. For analytical comparison, side-by-side sampling was conducted with and without the GFF.

Using remote air sampling pumps, area air samples were collected inside greenhouse growing sections #3 and #6 and in the main hallway. Because nicotine concentrations were expected to be high, especially during the beginning of the fumigation period, two XAD-4 tubes connected in series were used for the first four sampling periods in all three sampling locations. In each of the greenhouse sections, sampling periods ranged from 5 minutes (10 minutes after the start of fumigation) to 60 minutes (720 minutes into the fumigation period). Sampling periods and times were longer and later for the hallway because concentrations were expected to be lower in that location (see Table I). Sampling periods were increased sequentially following the start of fumigation to ensure sufficient detection limits for the expected drop in nicotine concentration. Single XAD-4 tubes were used to collect samples later in the fumigation period, in the airlock between the greenhouse and the rest of the laboratory, and outside near the exhaust fan of greenhouse section #3. Single XAD-4 tubes were also used to collect PBZ samples from the employee who lights the fumigant, the employee who unlocks the greenhouse the morning following fumigation, and the employee responsible for turning on the mechanical exhaust fans. Following each sampling period, the GFFs were placed in amber glass vials and immediately desorbed in 1 milliliter (ml) of a modified ethyl acetate solution (containing 1% triethylamine). The XAD-4 tubes and GFFs were later analyzed by gas chromatography using a nitrogen phosphorous detector (GC-NPD).

TABLE I

Nicotine area air concentrations

Time after start of fumigation (minutes)#	Sampling period (minutes)	Sampling midpoint (minutes)§	Section #3 (mg/m^3)	Section #6 (mg/m^3)	Hallway (mg/m^3)	Airlock (mg/m^3)	Outside (mg/m^3)
Background	185	– 480	(0.000072)	ND	(0.000078)	ND	(0.000078)
Entire fumigation period	480	240	N/A	N/A	N/A	0.0065	0.0071
T = 10	5	12.5	3.3	2.7	N/A	N/A	N/A
T = 15	45-Hall*	37.5	N/A	N/A	0.16	N/A	N/A
T = 40	10	45	1.04	0.80	N/A	N/A	N/A
T = 60	15	67.5	0.31	0.48	N/A	N/A	N/A
T = 120	20/60-Hall*	130/150*	0.39	0.28	0.016	N/A	N/A
T = 240	20	250	0.26	0.094	N/A	N/A	N/A
T = 300	90-Hall*	345	N/A	N/A	0.0030	N/A	N/A
T = 360	30	375	0.13	0.058	N/A	N/A	N/A
T = 480	45/90-Hall*	502.5/525*	0.11	0.083	0.0029	N/A	N/A
T = 600	45/90-Hall*	622.5/645*	0.11	0.048	0.0017	N/A	N/A
T = 720	60	750	0.085	0.061	0.0035	N/A	N/A
Mechanical exhaust T = 780	150	855	0.0084	0.0097	ND	0.00089	0.0071
Normal greenhouse exhaust operations T = 945	245	1067.5	0.023	0.021	0.0045	0.0019	0.00022
Normal operations T = 1245	112	1301	N/A	N/A	0.0021	N/A	N/A
Normal operations T = 1455	624	1767	N/A	N/A	0.0017	N/A	N/A

Numbers in parentheses indicate that reported values fell between the LOD and the LOQ;
ND – not detected;
Hall* – denotes hallway sampling periods;
– the start of fumigation was 7:15 p.m. Friday evening; T = 10 then represents a sample period beginning 10 minutes after the start, or 7:25 p.m.;
§ – the midpoint equals sampling time plus one-half the sampling period.

It was hypothesized that during fumigation, nicotine may be present as a vapor but also possibly bound or adsorbed onto particulates generated by the fumigation. Therefore, particle counts were measured over the same time periods as nicotine concentrations to evaluate the correlation between them. Two Met One® laser particle counters (model 227) were used for this purpose, one in section #6 and one in the hallway. The Met One counts particles simultaneously in two size ranges (>0.3 micrometers (μ) and >1.0 μ were selected for this survey) at an operating rate of 2.8 lpm. Samples were collected for 10 seconds every 10 minutes throughout each sampling period.

Statistical Analysis

Correlation and regression analyses were used to evaluate the relationship between nicotine concentration (the dependent variable) and the linear and quadratic versions of particle count data from section #6 and the hallway. The purpose was to assess the possibility of using these data, which are faster and easier to obtain than nicotine air concentration data, to estimate residual nicotine concentrations, especially following fumigation, during the restricted-entry period. The preamble of the EPA WPS describes the need for development of rapid on-site methods for determining residual pesticide levels before workers re-enter pesticide-treated areas [40 CFR Parts 156 and 170].[1]

Skin Exposure Assessment

Pre-extracted sampling glove monitors made of 100 percent cotton were used to assess the potential for hand contact with nicotine for employees responsible for fumigation and post-fumigation work. Employees wore protective reusable nitrile gloves while performing their duties, and the sample glove monitors were worn under the workers' gloves to test for breakthrough. After sampling, glove monitors were placed in labeled amber jars and sealed with teflon®-lined caps. For each employee, left- and right-hand gloves were placed in separate jars (two jars per employee) and immediately desorbed with 50 ml of the ethyl acetate solution. The samples and field blanks were later analyzed by GC-NPD.

Surface Sampling

To assess residual nicotine contamination and potential skin exposure, wipe samples were collected on surfaces commonly used by greenhouse personnel, including garden hoses, tables, door and broom handles, plant leaves, and desktops. The samples were collected with $3'' \times 3''$ pre-extracted cotton gauze moistened with the ethyl acetate solution, and approximately 100 square centimeters (cm^2) of surface area were wiped with gauze. To prevent crosscontamination, the investigator donned a new pair of disposable protective gloves prior to collecting each sample. After collection, the samples and blanks were placed in labeled amber glass vials, immediately desorbed in 20 ml of ethyl acetate, and later analyzed by GC-NPD.

Evaluation Criteria

Nicotine

Nicotine is a colorless to pale yellow oily liquid, which slowly turns brown when exposed to air or light, and is used in agricultural settings as an insecticide against aphids and thrips. Nicotine is listed as an EPA toxicity category I insecticide, most acutely toxic (each category [I–IV] is an EPA-established hazard indicator used for labeling pesticide containers with human hazard signal words assigned by levels of toxicity of the pesticide), and as a restricted-use pesticide. Although organophosphate insecticides have largely replaced nicotine, two types of nicotine products, an alkaloid and a sulfate, are still marketed in very limited quantities. Nicotine alkaloid, the form used in the greenhouse, is relatively volatile and acts both by fumigation (the EPA defines a fumigant as any pesticide product that is a vapor or gas, or forms a vapor or gas on application, and whose method of pesticidal action is through the gaseous state) and direct contact.[3,4]

Exposures to nicotine can occur by inhalation, skin absorption, and ingestion. It is a potent and rapid-acting poison which is quickly absorbed from all routes of entry, including the skin. Small doses of nicotine cause nausea, vomiting, diarrhea, headache, dizziness, and neurological stimulation, resulting in tachycardia (rapid heartbeat), hypertension (high blood pressure), sweating, and salivation. With severe intoxication, exposure results in convulsions and cardiac arrhythmia (abnormal heartbeat). In fatal cases, death nearly always occurs within one hour and has occurred within a few minutes. Fatal occupational poisoning is relatively uncommon; however, milder cases, with vomiting and diarrhea the predominant symptoms, have occurred among chemical processors and insecticide applicators. Nicotine poisoning was particularly common in the 1920s and 1930s when it was used more frequently as an insecticide.[5]

The NIOSH REL, OSHA PEL, and ACGIH® TLV® for nicotine are all 8-hour TWA concentrations of 0.5 milligrams per cubic meter (mg/m^3).[6,7] Each criterion also carries a "skin" notation, which refers to the potential significant contribution to the overall exposure by the cutaneous route, including the mucous membranes and eyes, mostly by direct contact with the substance. Nicotine is also listed in NIOSH pesticide category Group I (most hazardous) because of its potential for posing a significant risk of adverse acute health effects at low concentrations.[8]

According to the EPA WPS, in general, a 48-hour restricted entry internal (REI) is established for any product containing an active ingredient that is in toxicity category I because of dermal toxicity or skin or eye irritation. An REI is defined as the time after the end of a pesticide application during which entry to the treated area is restricted. REIs are established based on the acute toxicity of the technical grade of the active ingredients in the product and are determined by comparing the obtainable data on the acute dermal toxicity, eye irritation effects, and skin irritation effects of the

ingredient to the criteria of § 156.10(h)(1) [40 CFR Parts 156 and 170].[1]

Skin Exposure

Exposure standards, guidelines, or recommendations by NIOSH or regulatory agencies have not been established for pesticides on skin or work clothes. However, skin exposures are often a more important contributor to total pesticide exposure than inhalation exposures.[9-11] Loosely bound residues on plant material can be a major source of exposure for workers.[12,13] In general, hand exposure represents a major fraction of total skin exposure.[14] Evaluation of the amount of material potentially available for absorption can provide estimates of skin exposure. Additionally, these types of assessments are useful for evaluating the need for and efficacy of control measures, including personal protective equipment (PPE). There are numerous techniques available to estimate the potential for skin contact; however, there is no standard protocol for the assessment of the degree of skin contact or the interpretation of results.

Surface Contamination

Standards for interpreting surface contamination by pesticides have not been established. Risks associated with residual pesticide contamination are difficult to assess. Absorption (and resultant health effects) depend on the amount and conditions of contact between skin and contaminated surface. The wide range of such conditions makes it difficult to determine "safe" levels or meaningful exposure limits. Assessments that have been conducted often involve making assumptions about skin contact, absorption, and transfer rate to estimate a potential dose received.[15] These studies have usually been conducted to assess the health risk to children (toddlers) in buildings. The risk is generally higher after recent application and will vary depending on the type of pesticide treatment (e.g, crack and crevice, broadcast, or fogging).

Environmental Protection Agency—Worker Protection Standard

In 1992, the EPA issued final revisions to its regulations governing the protection of workers from exposure to agricultural pesticides. The revisions are included in 40 CFR, Part 156, which covers pesticide labeling requirements, and Part 170, the Worker Protection Standard. These regulations are intended to reduce the potential for pesticide poisonings and injuries among employees who work with pesticides in any capacity. The scope of the standard has been expanded to include workers performing hand labor in fields and forests treated with pesticides and nurseries and greenhouses that contain treated plants. Employees who handle pesticides (mix, apply, etc.) for use in these locations are also included. The regulations include requirements for warnings about applications, use of PPE, and restrictions on entry to treated areas. Pesticide registrants are now required to include appropriate labeling statements referencing these regulations, with specific application restrictions, REIs, PPE, and worker notification of pesticide applications.

Results

The employee responsible for igniting the fumigation containers had a personal breathing zone (PBZ) nicotine concentration of 0.0026 mg/m^3 during this 30-minute task; nicotine was not detected (minimum detectable concentration was 0.00018 mg/m^3) in the 5-minute PBZ sample collected on the employee unlocking the greenhouse doors following the fumigation process; and the employee responsible for the mechanical exhaust process had a PBZ nicotine concentration of 0.15 mg/m^3 during this 20-minute period. Nicotine was not detected on any of the glove monitors that were collected from these employees (the limit of detection [LOD] was 0.014 micrograms per sample [μg/sample]).

The results for the area air samples are compiled in Table I. Twenty samples were collected with two XAD-4 tubes in series, and final concentrations were obtained by adding the front and back tube results. Nicotine concentrations collected on the back tubes ranged from 0–14 percent of those found on the respective front tube, with a mean of 1.5 percent. Breakthrough from the front section to the back section of each of the front sampling tubes was reported to be less than 10 percent; therefore it is likely that because of the increased sampling flow rate, nicotine was pulled through the front tube onto the back tube during the sampling period. The GFFs were visibly discolored after sampling, but nicotine concentrations were reported either to be ND or trace levels (between the LOD of 0.014 μg/sample and the limit of quantitation [LOQ] of 0.40 μg/sample). Because no significant amounts of particle-bound nicotine were detected on any of the GFF samples and because most of the samples were collected without GFFs, reported results include only those samples collected without GFFs.

Prior to fumigation (background), nicotine concentrations ranged from ND in the airlock and section #6 to trace amounts in the greenhouse hallway and outside. During the 13-hour fumigation, nicotine concentrations in section #3 ranged from 0.085 to 3.3 mg/m^3, in section #6 from 0.048 to 2.7 mg/m^3, and in the hallway from 0.0017 to 0.16 mg/m^3. Samples collected over the entire fumigation period in the airlock and outside reflected nicotine concentrations of 0.0065 mg/m^3 and 0.0071 mg/m^3, respectively. During the 2½-hour mechanical exhaust of the greenhouse, nicotine concentrations ranged from ND in the hall to 0.0097 mg/m^3 in section #6. Samples collected in the airlock and outside the greenhouse during mechanical exhaust reflected nicotine concentrations of 0.00089 mg/m^3 and 0.0071 mg/m^3, respectively. Nicotine concentrations during the four hours following mechanical exhaust of the greenhouse ranged from 0.0045 mg/m^3 in the hall to 0.023 mg/m^3 in section #3. Concentrations in the airlock and outside were 0.0019 mg/m^3 and 0.00022 mg/m^3, respectively. A sample taken in the hallway from 20 to 22 hours after the start of fumigation showed a

nicotine concentration of 0.0021 mg/m^3, and one taken from 24 to 35 hours following the start of fumigation in the same location was 0.0017 mg/m^3.

When the nicotine concentration data from sections #3 and #6 were compared, the results showed that even under identical fumigation and sampling conditions, the concentrations in section #6 were consistently about 80 percent of those found in section #3.

Particle Monitoring

The distribution of the nicotine concentrations appeared to be normal (Gaussian) for the sampled particle size ranges ($> 0.3\ \mu$ and $> 1.0\ \mu$) following statistical analysis (residuals from model fitting). (Residual values are calculated by subtracting the actual sample results from the results predicted given a certain statistical model.) So for both section #6 and the hallway data, the dependent variable (nicotine concentration) was regressed against each particle size range. (A quadratic model was also fit and found to be non-significant for each combination). In both locations, nicotine concentration was found to be linearly related to each particle size range, and equations were developed to predict the nicotine concentration given a certain particle count. Based on those equations, predicted nicotine concentrations were compared to the actual concentration data from both locations, and percent error (the magnitude by which the predicted values differ from the observed values expressed as a percentage of the observed) ranged from 0.5 to 434 percent (mean of 85%) for section #6 and from 0.019 to 4791 percent (mean of 553%) for the hallway. It should be noted that statistical accuracy is limited in this study because the sample size was small (8 samples were used from section #6; 9 samples from the hallway).

Wipe Samples

Nicotine was detected on 21 of the 24 wipe samples (Table II). Prior to fumigation, nicotine levels ranged from ND to 3.38 micrograms per one hundred square centimeters of sampled area (μg/100 cm^2). The samples collected in the same locations after fumigation had nicotine levels ranging from 4.85 to 78.8 μg/100 cm^2.

TABLE II
Nicotine on wipe samples (μg/100 cm^2)

Sample location	Prior to fumigation	After fumigation
Stainless workbench surface between greenhouse sections #2 and #4 in hallway	ND	4.85
Hallway window crank handle in front of section #3	1.27	43.4
Broom handle inside section #3	3.38	36.4
Hose handle inside section #3	1.32	78.8
Hallway window crank handle in front of section #6	1.07	42.0
Hose handle inside section #6	ND	11.0
Inside door handle of section #6	2.29	29.8
Hallway drinking fountain	(0.87)	13.3
Five leaves from vinca plant in section #6	1.59	5.11
Greenhouse manager's desk surface	(0.76)	23.8
Top of refrigerator in airlock	2.40	9.60

ND is non-detectable;
Numbers in parentheses indicate that reported values fell between the LOD (0.014 μg/sample) and LOQ (1.00 μg/sample).

Discussion

PBZ results indicated that none of the employees was exposed to concentrations of airborne nicotine in excess of the occupational exposure levels, and nicotine was not detected on the glove monitor samples inside the protective gloves. Results from this study also indicated that nicotine area air concentrations fell and remained below the occupational exposure criteria of 0.5 mg/m^3 within one hour after ignition of the fumigant container in both greenhouse sections, and that concentrations in the hallway remained below the criteria throughout the fumigation period. Wipe samples, however, indicated the potential for significant skin exposure for greenhouse personnel.

Particle count data were not useful predictors of accurate nicotine concentrations and therefore are not useful determinants for safely re-entering the greenhouse. The prediction models (equations) developed were based upon the best fit for the collected data and resulted in errors between the observed and predicted values too large and widely varied to be useful. Note too that particle count data is non-specific and includes *all* sampled particles above the specified cut point in the sampling environment, not just those containing nicotine, and that a number of environmental factors will influence particle counts, size ranges, and distributions in any sampling period. (Factors that may influence particle count data include ventilation, employee movement or assigned duties, and the season of the year [i.e., pollen in the spring]). The results of this study, specifically the GFF sampling results, suggest that nicotine is particle-bound for only a very short time period, if at all, and that following the start of fumigation, nicotine is found in the vapor phase. The particles detected were likely combustion products of the fumigants' "inert" ingredients.

Measurement of particles (real numbers) also does not appear to be useful in determining when it is safe to re-enter the greenhouse. Particle counts had not

returned to background levels even 40 hours after the start of fumigation while nicotine concentrations were well below occupational exposure levels during this time.

Although this evaluation did not demonstrate a measurable nicotine health hazard one hour after the start of fumigation, it should be noted that there are regulatory criteria which still apply. As an EPA toxicity category I insecticide, nicotine has a 48-hour REI. There is, however, an exception to the specified REI for pesticides classified as fumigants: Once one of six WPS ventilation criteria are met prior to entry by any person, other than a properly trained and equipped handler (a handler, according to the WPS, is a person who enters fumigated areas to facilitate ventilation by manipulating ventilation systems in greenhouses), then the vapors are considered to be dispersed, and the REI is lifted. The ventilation criteria are:

- Ten air changes are completed;
- Two hours of ventilation using fans or other mechanical ventilation systems;
- Four hours of ventilation using vents, windows, or other passive ventilation systems;
- Eleven hours with no ventilation, followed by one hour of mechanical ventilation;
- Eleven hours with no ventilation, followed by two hours of passive ventilation; or
- Twenty-four hours with no ventilation [40 CFR Parts 156 and 170].[1]

Because the procedure of the greenhouse employees is to mechanically ventilate the greenhouse for 2–3 hours, 12–13 hours after the start of fumigation, the REI for this pesticide would be met once the mechanical exhaust is completed. The Fulex nicotine fumigant is classified as a fumigant from a regulatory standpoint, however, it also acts by direct contact.[16] The wipe samples collected after fumigation found surface contamination at levels up to 60 times higher than before fumigation, indicating increased potential for skin exposure. The decay time for nicotine on surfaces was not studied during this evaluation, however, according to the pesticide application record posted in the greenhouse, nicotine had not been used for three months. Almost three months later, 9 of the 12 wipe samples that were collected prior to the November fumigation still contained detectable amounts of nicotine.

The employee responsible for operating the mechanical exhaust ventilation following the fumigation period would be considered a "handler" according to the WPS and must be adequately protected while inside the treated area. The suplemental product label states that PPE for entry by handlers before WPS ventilation criteria have been met are coveralls over long-sleeved shirt and long pants, waterproof gloves, chemical-resistant footwear plus socks, protective eyewear, chemical-resistant headgear for overhead exposure (i.e., drips from liquid pesticide applications), and a respirator with either an organic vapor-removing cartridge with a pre-filter approved for pesticides (MSHA/NIOSH approval number prefix TC-23C), or a canister approved for pesticides (MSHA/NIOSH approval number prefix TC-14G).[17] The results from this study suggest that no airborne nicotine or overhead exposure hazards exist after one hour into the fumigation period and that employees would be adequately protected during the REI wearing long-sleeve shirts and pants, and waterproof gloves and boots, as is the current practice.

However, there are specific factors associated with a fumigation which limit the findings of this evaluation, and further studies are necessary to make this determination. Factors which may influence fumigant concentrations include temperature and humidity within the greenhouse and outdoors, wind velocity, atmospheric pressure, ventilation, number and placement of fumigant containers, and whether or not the container contents completely burn after ignition. Sampling results showed obvious fumigant concentration differences between sections #3 and #6, where each had a fumigant container that burned completely, despite their identical size, structure, and sampling equipment setup. Therefore, employees should continue to follow WPS regulations.

Conclusions

Sampling results from this study suggest that in this case, EPA WPS PPE requirements for greenhouse entry during the REI might have been unncessarily restrictive. The results from this investigation are limited, however, so that this study alone is an insufficient basis for changing the PPE requirements. Additional studies could provide evidence for those changes. In the meantime, employees should follow current EPA regulations. Because of the hazard for skin exposure to nicotine, all greenhouse personnel should be adequately protected while performing any greenhouse duties.

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