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A. W. Dimock Laboratory
Cornell University
Ithaca, New York

Ann M. Krake, M.S.

PREFACE

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ACKNOWLEDGMENTS AND AVAILABILITY OF REPORT

This report was prepared by Ann M. Krake of the Hazard Evaluations and Technical Assistance Branch, Division of Surveillance, Hazard Evaluations and Field Studies (DSHEFS). Field assistance was provided by Max Kiefer. Chemical analytical support was provided by Stephanie M. Pendergrass of the Measurements Support Section and Ardith A. Grote of the Measurements Development Section, Methods Research Branch, Division of Physical Sciences and Engineering, NIOSH. Statistical support was provided by Marty Petersen, Statistical Services Section, Support Services Branch, DSHEFS. Desktop publishing was performed by Ellen E. Blythe.

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Cornell University
Ithaca, New York
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SUMMARY

On November 21–24, 1996, National Institute for Occupational Safety and Health (NIOSH) representatives conducted a health hazard evaluation at Cornell University in Ithaca, New York, in response to a request submitted by the manager of Cornell's occupational health and safety program. The request concerned potential exposures of greenhouse employees and researchers to the insecticide nicotine during maintenance and manipulation of research plants. There were no reported health problems; however, management was concerned that employees were re–entering the greenhouse before nicotine concentrations had decreased to a safe level.

Personal breathing zone samples collected for three greenhouse employees associated with the fumigation process ranged from non–detectable to 0.15 milligrams per cubic meter (mg/m^3) and indicated that none of the employees were exposed to nicotine concentrations exceeding applicable occupational exposure limits (0.5 mg/m^3). Area air samples were collected for nicotine in two greenhouse sections and in the main hallway connecting the sections before, during, and after a 13–hour fumigation process. Sampling results indicated that nicotine concentrations inside the sections peaked at 3.3 mg/m^3 within 10 minutes of the start of fumigation but fell within 40 minutes and were less than 0.5 mg/m^3 within one hour after fumigation began. Nicotine concentrations in the connecting hallway remained low (0.0017–0.16 mg/m^3) throughout the fumigation. Wipe samples collected on commonly used surfaces in the greenhouse before and after fumigation showed that residual nicotine levels in some locations were almost 60 times higher after fumigation.

Personal breathing zone and area air samples collected during and after a nicotine fumigation process showed that airborne nicotine concentrations did not represent a hazard to greenhouse personnel; however, wipe samples collected on commonly utilized surfaces after the fumigation found residual nicotine. Because nicotine is readily absorbed through the skin, employees may be exposed to nicotine when they touch and use greenhouse surfaces and equipment. Recommendations are made in the report to remove or cover portable tools and hoses during fumigation, and to use personal protective equipment (gloves) and good hygiene practices.

Keywords: SIC 0181 (Ornamental floriculture and nursery products); greenhouse, nicotine, insecticide, pesticide, fumigation.

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INTRODUCTION

On November 8, 1995, the National Institute for Occupational Safety and Health (NIOSH) received a request from Cornell University's occupational health and safety program manager for a health hazard evaluation (HHE) at the A. W. Dimock Laboratory, Cornell University, in Ithaca, New York. The request asked NIOSH to assess potential employee exposures to the fumigant nicotine following fumigation and during maintenance and manipulation of greenhouse research plants.

During November 21–24, 1996, NIOSH representatives conducted an evaluation of the fumigation process in the Dimock Laboratory greenhouse. 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 Dimock research laboratory is located on the campus of Cornell University and is part of the College of Agriculture and Life Science. The facility includes a greenhouse with eight–900 cubic feet (ft^3) growing sections and a laboratory, which are connected at one end by a hallway with doors that form an airlock. Each greenhouse section is equipped with one 24–inch exhaust fan located opposite the entrance to the section on the outside wall. The greenhouse contains a variety of plants used to study the transmission of viruses by aphid vectors. Nicotine alkaloid (1–methyl–2((3–pyridyl)pyrrolidine) is used in a biweekly rotation, about every six weeks, with two other fumigants, dithio (tetraethyldithiophosphate) and dichlorvos (dimethy 2,2–dichlorovinyl phosphate). Fumigations typically take place every other Friday evening at 7 p.m. Other greenhouse pesticides, including aerosols, fogs, and soil–directed applicants, are used on a weekly or daily basis as needed.

The fumigation procedure is designed to adhere to the Environmental Protection Agency's (EPA) Worker Protection Standard (WPS) [40 CFR[a] Parts 156 and 170 (1992)],[1] and the University's occupational safety and health program. Prior to fumigation, warning signs, which include emergency personnel contact information, fumigation material, and the dates and times the facility will be closed and re–opened, are posted on every door leading into the greenhouse area. All entry doors are locked, all greenhouse exhaust fans are disabled at the breaker, all window vents are closed, and two trained employees are present at all times during the lighting of the fumigant containers. The employee primarily responsible for fumigation is 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) are worn during container activation. The nicotine fumigant (Fulex® Nicotine Fumigator, Fuller System, Incorporated, Woburn, Massachusetts, EPA Registration Number 1327–33) is packaged in a six–ounce can and contains 14% nicotine alkaloid and 86% inert ingredients, which include 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 is started by shaking the can, placing the can on the floor near the middle of each greenhouse section, lighting a sparkler

[a] *Code of Federal Regulations*. See CFR in references.

near the handle end with a propane torch, and placing the sparkler slowly into the mixture in the can. The fumigator starts at the furthest end of the greenhouse from the exit, igniting each can, and closing each section door behind him as he goes. This process takes approximately 15 minutes. The greenhouse is then locked for the next 12–13 hours.

All entry doors to the greenhouse remain locked until the next morning when, 12–13 hours following the start of fumigation, a greenhouse employee unlocks them without entering the greenhouse. Another employee, wearing coveralls, reusable waterproof gloves, and rubber boots, spends 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 enters each greenhouse section to collect spent fumigant containers, which are sealed in plastic bags and placed in the garbage dumpster; containers that do not burn are recapped and used for the next fumigation. The greenhouse is left to mechanically exhaust (ventilate) for a period of 2–3 hours, after which time the employee returns to water plants, wearing coveralls and rubber boots, but no gloves. The fumigation warning signs usually remain 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

Area and Personal Breathing Zone Air Sampling

The fumigation and sampling schedules followed during the NIOSH evaluation were:

November 22: 9:30 a.m. –12:30 p.m.
— background samples and particle count (PC) data collected;

November 22–23: 7:15 p.m. – 8:15 a.m.
— fumigation of greenhouse, fumigation samples and PC data collected;

November 23: 8:15 a.m. – 10:50 a.m.
— mechanical exhaust of greenhouse, exhaust samples and PC data collected;

November 23–24: 10:50 a.m. – 10:15 a.m.
— regular greenhouse operation, post–fumigation samples and PC data collected.

A newly developed NIOSH sampling and analytical method for nicotine in environmental tobacco smoke was used to collect and analyze personal breathing zone (PBZ) and area air samples inside and outside the greenhouse.[2] The method was developed to account for the lower nicotine concentrations found in environmental tobacco smoke and the higher nicotine concentrations expected in this situation. This new method, 2551, replaces method 2544 and is due to be published in October 1997. 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 1). 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. PBZ and area air samples were collected with SKC, Incorporated® programmable universal–flow sampling pumps, model 224–PCXR7, calibrated to operate at 1.0 lpm.

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).

We 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 in order 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 (1992)].

Approximately eight minutes into the fumigation period in section #6, particle count levels exceeded the capacity of the Met One®, and a sensor failure occurred for the next 11 sampling periods (about one hour and 45 minutes). Approximately 20 minutes into the fumigation period in the hallway, a similar sensor failure occurred for about one hour. Particle count data collected during the sensor failures were not included in the statistical analyses.

EVALUATION CRITERIA

Skin Exposure Assessment

Pre–extracted sampling glove monitors made of 100% 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 desk tops. The samples were collected with 3" x 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 cross-contamination, 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.

As a guide to the evaluation of the hazards posed by workplace exposures, NIOSH field staff employ environmental evaluation criteria for the assessment of a number of chemical and physical agents. The primary sources of environmental evaluation criteria for the workplace are: (1) NIOSH Recommended Exposure Limits (RELs),[3] (2) the American Conference of Governmental Industrial Hygienists' (ACGIH®) Threshold Limit Values (TLVs®),[4] and (3) the U.S. Department of Labor, OSHA Permissible Exposure Limits (PELs) [29 CFR 1910.1000 (1989)]. In July 1992, the 11th Circuit Court of Appeals vacated the 1989 OSHA PEL Air Contaminants Standard. OSHA is currently enforcing the 1971 standards which are listed as transitional values in the current Code of Federal Regulations; however, some states operating their own OSHA–approved job safety and health programs continue to enforce the 1989 limits. NIOSH encourages employers to follow the 1989 OSHA limits, the NIOSH RELs, the ACGIH TLVs, or whichever are the more protective criteria. The OSHA PELs reflect the feasibility of controlling exposures in various industries where the agents are used, whereas NIOSH RELs are based primarily on concerns relating to the prevention of occupational disease. It should be noted when reviewing this report that employers are legally required to meet those levels specified by an OSHA standard and that the OSHA PELs included in this report reflect the 1971 values.

These criteria are intended to suggest levels of exposure to which most workers may be exposed up to 10 hours per day, 40 hours per week for a working lifetime without experiencing adverse health effects. It is, however, important to note that not all workers will be protected from adverse health effects even though their exposures are maintained below these levels. A small percentage may experience adverse health effects because of individual susceptibility, a pre-existing medical condition, and/or a hypersensitivity (allergy). In addition, some hazardous substances may act in combination with other workplace exposures, the general environment, or with medications or personal habits of the worker to produce health effects even if the occupational exposures are controlled at the level set by the criterion. These combined effects are often not considered in the evaluation criteria. Also, some substances are absorbed by direct contact with the skin and mucous membranes, and thus overall exposure is potentially increased. Finally, evaluation criteria may change over the years as new information on the toxic effects of an agent become available.

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 personal protective equipment (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, restricted–entry intervals (REIs), PPE, and worker notification of pesticide applications.

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[b]) 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 Dimock greenhouse, is relatively volatile and acts both by fumigation[c] and direct contact.[5,6]

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.[7]

The NIOSH REL, OSHA PEL, and ACGIH TLV for nicotine are all 8–hour TWA concentrations of 0.5 mg/m^3. 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 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

[b] 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.

[c] 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.

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 (1992)].

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.[9,10,11] 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 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).

RESULTS

PBZ, Glove Monitor, and Area Air Sampling

The employee responsible for igniting the fumigation containers had a 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 1. 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% of those found on the respective front tube, with a mean of 1.5%. Breakthrough from the front section to the back section of each of the front sampling tubes was reported to be less than 10%; 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% 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 μ and >1.0 μ) following statistical analysis (residuals from model fitting[d]). 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% (mean of 85%) for section #6 and from 0.019 to 4,791% (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 2). Prior to fumigation, nicotine levels ranged from ND to 3.38 micrograms per one hundred square centimeters of sampled area ($\mu g/100\ cm^2$). The samples collected in the same locations after fumigation had nicotine levels ranging from 4.85 to 78.8 $\mu g/100\ cm^2$.

Workplace Observations

The greenhouse doors were unlocked

[d] Residual values are calculated by subtracting the actual sample results from the results predicted given a certain statistical model.

immediately following the fumigation period and left that way during the mechanical exhaust cycle and thereafter. Several researchers and other greenhouse employees, one accompanied by a child, entered the greenhouse sections at various times following the mechanical exhaust to work with the plants.

DISCUSSION

PBZ results indicated that none of the employees were 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.[e] 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,[f] 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;

[e] 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).

[f] A handler, according to the WPS, is a person who enters fumigated areas to facilitate ventilation by manipulating ventilation systems in greenhouses.

— Twenty–four hours with no ventilation [40 CFR Parts 156 and 170 (1992)].

Because the procedure of the Dimock 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 was last used as a fumigant on August 30, 1996. 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 supplemental 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 unnecessarily 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.

RECOMMENDATIONS

The following recommendations are offered based upon results obtained and observations made during the evaluation. The recommendations are intended to improve safety and help prevent hazardous exposures to nicotine following the fumigation process.

1. Although there are no standards for surface contaminants, the REI for category I toxicants is based partly upon their acute systemic effects from skin absorption. Because nicotine is present in much higher amounts on exposed surfaces following fumigation, several recommendations are made to prevent skin exposures:

- ✦ Ensure that all personnel who enter the greenhouse are aware of the potential for skin contact;

- ✦ Because of the frequency of pesticide application in the greenhouse, and because children are lower in body weight and potentially at increased risk for absorbing a toxic amount of nicotine through the skin, they should be kept out of the greenhouse;

- ✦ All portable tools and equipment in the greenhouse should be covered or removed to a contaminant–free environment for the duration of the fumigation period. This would include hoses, brooms, and other gardening implements;

- ✦ Contact with contaminated surfaces should be avoided, and protective gloves such as a disposable nitrile type should be used whenever contact is required. (Because of the frequency of fumigation and other pesticide applications, gloves should be worn whenever contaminated surfaces are touched, especially plants);

- ✦ All contaminated work surfaces, including tables, desks, and drinking fountains, should be cleaned with water after the fumigation;

- ✦ Good hygiene practices, such as hand–washing and refraining from eating, drinking, and smoking inside the greenhouse, should always be observed.

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Table 1 Nicotine Area Air Concentrations Dimock Research Greenhouse November 22–24, 1996 HETA 96–0032							
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	1,067.5	0.023	0.021	0.0045	0.0019	0.00022
Normal operations T = 1,245	112	1,301	N/A	N/A	0.0021	N/A	N/A
Normal operations T = 1,455	624	1,767	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.

Table 2 Nicotine on Wipe Samples (μg/100 cm^2) Dimock Research Greenhouse November 22–24, 1996 HETA 96–0032		
Sample Location	Prior to Fumigation	After Fumigation
Stainless work bench 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).

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