DETERMINATION OF AIRBORNE CONCENTRATIONS OF DICHLORVOS OVER A RANGE OF TEMPERATURES WHEN USING COMMERCIALLY AVAILABLE PESTICIDE STRIPS IN A SIMULATED MILITARY GUARD POST

by

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DEDICATION

I would like to dedicate my thesis to my Wife Jessica, for her patience, support, and understanding through out this process.

-Mark

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ABSTRACT

DETERMINATION OF AIRBORNE CONCENTRATIONS OF DICHLORVOS OVER A RANGE OF TEMPERATURES WHEN USING COMMERCIALLY AVAILABLE PESTICIDE STRIPS IN A SIMULATED MILITARY GUARD POST

LT Mark A. Otto, MSPH, 2013

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Potential inhalational exposure to dichlorvos vapor associated with using commercially-based dichlorvos-impregnated resin strips (Nuvan Prostrips) in a simulated military guard post was evaluated. A varying number of these pesticide strips, ranging from the manufacturer's guidelines ((3)-16 gram (g) strips) up to (12)-16 g strips, were placed in a small, enclosed space similar in size to a typical military guard post and static sampling simulating personal air sampling was conducted, followed by analysis using the OSHA Method 62. Air sampling was conducted within the space at discrete temperatures in the range of 26 ˚C to 38 ˚C to determine the airborne concentration generated at each temperature setting. Airborne concentrations were compared to established military exposure guidelines (MEGs) and the 8-hour OSHA permissible exposure limit (PEL) for dichlorvos (0.99 mg/m^3). Findings indicated that exceeding the recommended number of strips as per manufacturer's recommendations for the specific

workspace volume and environmental conditions produced airborne dichlorvos concentrations above established occupational standards (1.77-3.70 mg/m^3). Such exposures may potentially lead to adverse effects, such as loss of mental and visual acuity for the guard post watch standers. However, concentrations of airborne dichlorvos generated when adhering to manufacturer's guidelines based on workspace volume resulted in levels of 0.16-0.39 mg/m^3, which were below the established occupational health limits. While dichlorvos-impregnated strips are not currently recommended for use in manned workspaces for periods > 4 hours, findings suggest that prolonged use (8 hours) of similar pesticide strips within manned spaces to kill disease-carrying insects may be a viable and safe option under similar conditions and in accordance with manufacturer's guidelines.

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STATEMENT OF PROBLEM

Armies throughout the course of history have been afflicted by vector borne diseases such as plague, yellow fever, typhus, malaria, dengue fever, and West Nile Virus (27). With the historical public health problems associated with deployed US forces from disease-transmitting insects, it is necessary to protect Soldiers, Sailors, Airmen, and Marines from biting insects, such as mosquitoes and sand flies.

Currently, in the Afghanistan area of operations (AO), there is an intermediate to high risk for vector-borne infectious diseases such as malaria, sand fly fever, and leishmaniasis (22). The environmental conditions most favorable for the spread of the aforementioned diseases occur during the Spring through Fall seasons (months of March to October) when the average temperatures range from 16 °C to 41 °C (21).

Given the necessity of protecting service members from disease transmitting insects, continuously seeking effective approaches in preventing vector borne disease is paramount. One such approach being considered for personal protection is Nuvan Prostrips (AMVAC Chemical Corporation, Los Angeles, CA) (2) are resin-based strips containing 18.6% dichlorvos by weight, and are approved for use by the US Environmental Protection Agency (EPA) to kill flies, mosquitoes, gnats, bedbugs, and other arthropod pests. Available in two sizes, the strips are hung in an enclosed room with the 16 g version is used to treat areas of 100-200 ft^3 and the 65 g version is used to treat areas of 900-1200 ft^3. According to the Nuvan Prostrips manufacturer, the dichlorvos-impregnated resin strips slowly release the compound into the air for up to four months into an enclosed air space (2).

SIGNIFICANCE

Recently, the DoD Armed Forces Pest Management Board (AFPMB) has expressed an interest in the use of Nuvan Prostrips for their potential use to kill insects within forward-deployed guard posts, as such posts may be located in areas in which a multitude of vector borne diseases are endemic (7). The application of pesticide strips in this occupational manner represents a use that would be outside of normal manufacturer's guidelines for the dichlorvos-impregnated strip, as the strips are recommended for use in unmanned spaces. The potential human exposure risk associated with this application has not been characterized.

RESEARCH OBJECTIVES

The purpose of this study (Table 1) was to determine if 1-hour and 8-hour airborne military exposure guidelines (MEGs), established by the U.S. Army Public Health Command to protect human health (31), were exceeded when one or more dichlorvos-impregnated pesticide strips were placed within a small volume workspace, such as a small forward-deployed, naturally ventilated guard post. The Nuvan Prostrips were subjected to discrete temperature points within a range of temperatures (25 °C – 38 °C), with the higher temperatures representing those similar to what is found at forward deployed locations, to determine the airborne concentrations liberated from the strips under these respective conditions.

While this study will quantify the potential airborne exposure levels from manufacturer's recommended application of the Nuvan Prostrips, it is important to test the use of multiple strips due to the potential for overuse of a product based on the belief that if a little of something works and performs well, then more must work and perform even better. Knowing that directions for application may not be followed exactly, it is valuable to test the application of multiple strips, so that adequate warnings can be provided in application instructions. For these reasons, multiple strips were subjected to a high temperature to determine the airborne concentrations liberated from the strips. Combinations of Nuvan Prostrips resulting in total weights of 48 g (8.9 g dichlorvos by weight), 65 g (12.1 g dichlorvos by weight), 96 g (17.9 g dichlorvos by weight), and 192 g (35.7 g dichlorvos by weight) were subjected to the highest temperature achievable within the simulated guard post (38 °C) and airborne concentrations were measured.

Table 1. Research Aims

Experiment	Description
1. Evaluate Effects of Increased Temperature on Airborne Concentration when using Constant Mass of Dichlorvos	(3)-16 g Nuvan Prostrips (Manufacturer's recommendation based on space size) were placed in enclosed space with temperatures of 26 °C, 28 °C, 35 °C, 38 °C, respectively
2. Evaluate Effects of Increased Mass of Dichlorvos on Airborne Concentration at Single, Discrete, High Temperature	At 38 °C, increasing masses of Nuvan Prostrips (48 g, 65 g, 96 g, 192 g) were used in the enclosed space

CHAPTER 2: LITERATURE REVIEW

MILITARY OPERATIONS

Guard posts in deployed settings are manned by trained and armed security personnel to protect bases and outposts where military personnel are deployed. The guard post can either be built to specific requirements or can be a standardized, commercial off the shelf product such as the HESCO guard post (10) (Figure 1). Typical shifts for watch standers (personnel who stand shifts to guard the base) are six to eight hours; however, the watch duration is dependent on the number of personnel available to rotate positions and current operations, so shifts can be extended (8; 10; 17). Watch standers will typically stand the shifts for 7 consecutive days, followed by a break for 7 days (8).

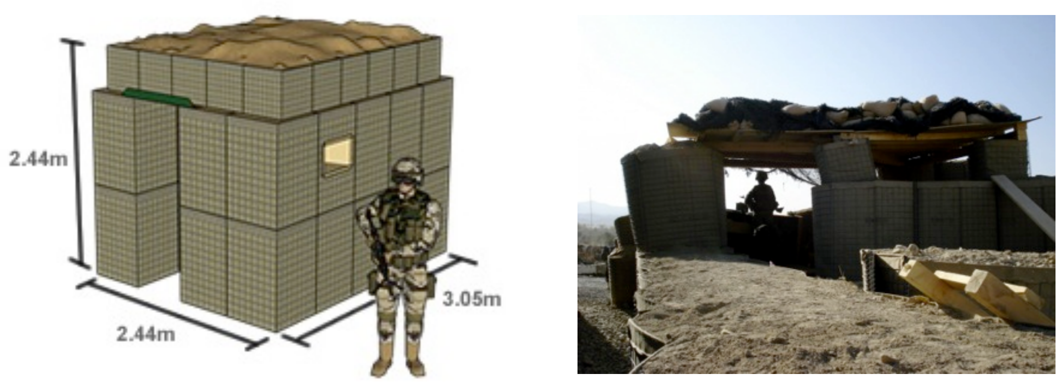

Figure 1. Military Guard Posts

Many vector borne disease threats can be mitigated through modern vaccination programs, avoidance of insect infested areas, and prophylaxis treatment of exposed personnel deployed in endemic disease areas. Additionally, the use of permethrin treated uniforms and bed nets, as well as skin application of N,N-Diethyl-meta-toluamide (DEET) to repel biting insects, further assists in protecting exposed personnel. Buildings and areas are also protected from insects by certified pesticide applicators spraying pesticides around the areas of concern. However, there remains room for improvement. For example, 26 US Service Members contracted malaria in Afghanistan from January to September 2012, and 91 US Service Members contracted the illness in 2011 (29). Due to the desire to further mitigate the number of vector borne diseases among troops, supplemental and/or alternate means of pesticide application in and around work environments relative to currently used approaches are continuously considered.

DICHLORVOS

Dichlorvos (Figure 2) is an organophosphorus (OP) insecticide (acetylcholinesterase (AChE) inhibitor), with a molecular weight of 220.98 g/mol, density of 1.415 g/cm^3 at 25 °C, and boiling point of 117 °C at 10 mm Hg (25). First registered in 1948 (1), it is used in the commercial pest management profession for control of pests in commercial and residential spaces. Manufacturers of dichlorvos recommend application of products containing the chemical in unoccupied spaces, due to the risk of adverse human health effects from inhalation or skin contact (11).

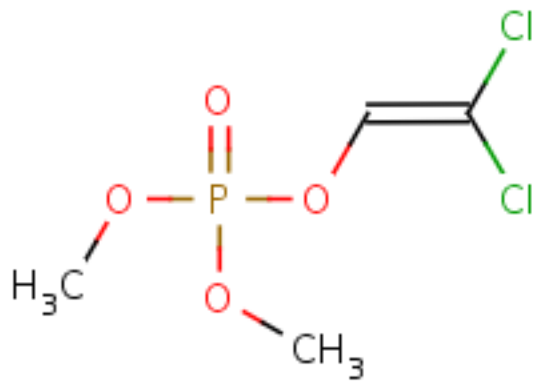

Figure 2. Dichlorvos (32)

Acetylcholinesterase (AChE) inhibitors, such as OP insecticides including dichlorvos, function by blocking AChE at nerve synapses. Because AChE is unable to hydrolyze acetylcholine (ACh), a buildup of ACh occurs at the synapses, leading to potentially serious and sometimes fatal consequences. Typical routes of entry for AChE inhibitors are ingestion, inhalation, and absorption, which then affects the eye, gastrointestinal (GI) tract, neuromuscular junction, and secretory glands, resulting in perspiration, nausea, vomiting, diarrhea, drowsiness, fatigue, headache, convulsions, and coma, and others. Dichlorvos crosses the blood-brain barrier allowing it to inhibit AChE throughout the central nervous system (6). Treatment for severe dichlorvos overexposure is atropine because it competes for the binding sites of ACh at the nerve synapses, followed by 2-pralodoxime chloride (2-PAM Cl) to remove the respective OP compound from AChE molecules, permitting the normal breakdown of ACh to occur (6). The biological half-life of inhaled dichlorvos in human blood is 8.1 minutes for males and 11.2 minutes for females (5).

The conditions that affect the liberation rate of dichlorvos from impregnated strips are the temperature, shape and size of the strip (surface area), humidity, and air movement, with temperature having the greatest effect (12; 13). Previous studies have demonstrated expected increases in vapor pressure of dichlorvos (0.032 mm Hg at 32 °C to 0.296 mm Hg at 60 °C) (12). The generation rate of dichlorvos from poly vinyl chloride (PVC) resin pesticide strips was determined to double for every 11.1 °C increase in room temperature (12). A bedbug study showed that the use of fans and space heaters when treating a dormitory room with Nuvan Prostrips resulted in a 70-fold increase in volatilization of dichlorvos from the strips (measured by weight loss of the strip) compared to room temperature (24 °C) and no fans (19).

Dichlorvos is only persistent in the atmosphere for a few hours because of its volatile nature (4) (half-life of dichlorvos vapor in the atmosphere is about 15 hours (32)); thus, its vapor will quickly degrade as it releases from the resin strip. It also degrades faster as temperature increases due to an increased rate of hydrolytic breakdown of dichlorvos with increasingly higher temperatures (13).

MILITARY EXPOSURE GUIDELINES

The U.S. Army's Technical Guide-230 (TG-230), developed by the U.S. Army Public Health Command (Aberdeen Proving Ground, MD), is a preventive medicine tool that provides information on how to assess and characterize potential risks posed from chemical exposures to deployed personnel (31). The TG-230 MEGs also provides "decision aids" in determining if deployed personnel are at significant risk. These aids are in the form of military exposure guidelines (MEGs), which are time- and severity-based exposure guidelines for chemicals in the air, soil, and water, with respective exposure durations ranging from minutes to months and severity ranging from negligible to catastrophic.

Regarding severity of exposure, the published airborne MEGs are organized regarding potential impacts on human health in the following categories: Negligible, Marginal, Critical, and Catastrophic. The Negligible category is defined as "*a continuous exposure to airborne concentrations (for 10 minutes, 1 hour, 8 hours, or 24 hours) above this MEG (but below the Marginal MEG) (which) could begin to produce mild, non-disabling, transient, reversible effects. Such effects, if any, will typically be mild irritant types of effects and/or initially be expected in personnel with underlying susceptibility factors (e.g., asthmatics). Effects are not expected to impair performance* (31)."

The Marginal category is defined as "*a continuous exposure to airborne concentrations (for 10 minutes, 1 hour, 8 hours, or 24 hours) above this MEG (but below the Critical MEG) (which) could begin to produce effects that may result in some performance degradation, especially for tasks requiring extreme mental/visual acuity or physical dexterity/strength amongst a portion of individuals* (31)."

The Critical category is defined as "*a continuous exposure to airborne concentrations (for 10 minutes, 1 hour, 8 hours, or 24 hours) above the MEG (but below the Catastrophic MEG) (which) could begin to result in serious health effects. This MEG is a conservative population threshold estimate of potential life-threatening or lethal effects; whereby, these effects are expected initially in personnel with underlying susceptibility factors* (31)."

The Catastrophic category is defined as "*a continuous exposure to airborne concentrations (for 10 minutes, 1 hour, 8 hours, or 24 hours) above the MEG (which) is anticipated to result in deaths and/or many personnel with severe incapacitating effects (overall greater than 50 percent mission/performance capability loss). Effects are likely to require medical treatment* (31)."

The MEG values for dichlorvos, to include the exposure durations and severity categories, are listed in Table 2. The acute health effects associated with exposure to dichlorvos vapor that could potentially affect watch standers include vision and nervous system impairment such as eye pain, problems with mental acuity, dizziness, headache, and convulsions (31). Initial adverse effects on watch standers from exposure to this compound could begin as early as the airborne concentrations found in the Negligible MEG category.

Table 2. Dichlorvos MEGs (31)
(There are not categories for Catastrophic, 8-Hour Critical, or 8-Hour Marginal for Dichlorvos).

	1-Hour Critical	1-Hour Marginal	1-Hour Negligible	8-Hour Negligible
Dichlorvos	72 mg/m^3	5.1 mg/m^3	0.99 mg/m^3	0.99 mg/m^3
Health Effects	Threshold for life threatening effects	Some performance degradation: mental, visual, dexterity, and strength	Cholinesterase inhibition	Cholinesterase inhibition

Of important note, the Negligible MEG value for exposure to dichlorvos is virtually the same as the regulatory exposure limit set by the U.S. Occupational Safety and Health Agency (OSHA). The OSHA Permissible Exposure limit (PEL) for dichlorvos is a regulatory occupational exposure value (legally enforceable, based on 8-hour workday, 5 days/week) and is set at 1 mg/m^3 for general industry, construction industry, and maritime industry. OSHA has also assigned a skin notation for a possible dermal route of exposure (26). The National Institute for Occupational Safety and Health (NIOSH) has also set the Recommended Exposure Limit (REL) (a non-legally binding guideline, based on a 10-hour workday, 40-hour workweek) for dichlorvos at 1 mg/m^3 and assigned a skin notation for contact with liquid dichlorvos (23; 24). Additionally, the American Conference of Governmental Industrial Hygienists (ACGIH) has assigned a Threshold Limit Value (TLV) (a non-legally binding guideline, based on exposures over a working lifetime) time-weighted average (TWA) of 0.1 mg/m^3 for inhalable aerosol and vapor. ACGIH assigned a skin notation due to dermal absorption representing a significant route of exposure, potentially leading to systemic symptoms of organophosphate poisoning following dermal contact (1).

From 1961-2002, the TLV-TWA was 0.9 mg/m^3, but was reduced to the current level of 0.1 mg/m^3, to provide a margin of safety for workers to dichlorvos' cholinergic effects. There was insufficient evidence to justify a TLV short term exposure limit (TLV-STEL), but ACGIH set the TLV-TWA low enough to protect workers from short term exposure peaks (1).

OCCUPATIONAL/RESIDENTIAL STUDIES

Human male volunteers and Rhesus monkeys were exposed to dichlorvos vapor over the course of four experiments aboard a simulated aircraft cabin in the 1960s. During the experiments, the humans and monkeys were exposed over a four day period for 1 or 2 hours per day to 0.49 mg/m^3 with no change in plasma cholinesterase or red blood cell cholinesterase was noted, and no miosis was evident in the humans. The same group was later exposed to concentrations of 2.1 mg/m^3 and slight drops in cholinesterase levels were noticed in the humans that were exposed for 2 hours per day and no miosis was noted in the humans or monkeys. The monkeys were exposed to concentrations of 12.9 mg/m^3 and miosis and depression of cholinesterase was noted (28).

A study in 1969 focused on the use of Vapona (18.5% Dichlorvos) insecticide strips in Italian hospitals. One strip was hung for every 1000 ft^3, as the manufacturer directed, and air samples were taken from multiple points in the room using air sampling pumps and a glass bubbler. Concentrations of airborne dichlorvos ranged from 0.04 mg/m^3 to 0.21 mg/m^3. Erythrocyte cholinesterase and plasma cholinesterase was measured from the exposed patients, showing no reduction of erythrocyte cholinesterase or plasma cholinesterase. The study concluded that there was no harm in using the insecticide strips in the hospital, but recommended it would be a good practice to ventilate the poorly ventilated rooms due to the inability of patients to leave the rooms (9).

An observational study, using before/after self-controls, conducted in the early 1970s in Switzerland, examined worker exposure to dichlorvos in a factory where workers processed and packaged dichlorvos-releasing vaporizers. The workers were exposed to an average of 0.7 mg/m^3 per day of airborne dichlorvos concentrations, over eight months. The maximum airborne concentration value recorded was 3.0 mg/m^3. It was found that concentration of plasma cholinesterase in the cohort was decreased by about 60% and erythrocyte acetyl cholinesterase levels were decreased by about 35% because dichlorvos binds to acetyl cholinesterase making it unavailable, but employee exposure was not linked to symptoms of over exposure. The study could not determine if the route of exposure to dichlorvos was inhalational or dermal (it was not clear if handling of dichlorvos occurred). The study concluded that a TLV of 1.0 mg/m^3 was acceptable, which agreed with ACGIH at the time of the study (1.0 mg/m^3) (20).

A two-year study conducted in the 1970s examined 26 homes in Arizona (the homes used evaporative coolers to cool the homes) on the use of Vapona insecticide strips (18.5% dichlorvos). Each home studied had an average of 7 to 11 Vapona insecticide strips placed in their home for 12 months, 6 months, or 1.5 months. The home occupants spent an average of 55% to 70% of their time indoors exposed to the strips. The average airborne concentration of dichlorvos was found to be 0.13 mg/m^3. When compared to the controls, the occupants of the homes showed no evidence of cholinesterase inhibition, which resulted in the researchers concluding that there was no hazard to the occupants or pesticide applicators using the strips homes (18).

A study of pesticide sprayers and occupants of residences, conducted in the mid-1980s looked at dermal and respiratory exposure to dichlorvos from spraying of 20 homes. Dermal exposure pads and collected hand washings were used to characterize the dermal exposure. The respiratory exposure was collected with personal air sampling pumps and impingers during spraying. Additionally, room air samplers operated in the homes for 24 hours after spraying to characterize the exposure of the residents, and blood samples were taken from a resident of each home at time 0 and 24 hours later. It was found that the applicator respiratory exposure was 2.1% (0.021 mg/m^3) of the ACGIH TLV (1.0 mg/m^3 at the time of the study), while the residential exposure was 21% (0.21 mg/m^3) of the TLV because of longer exposure after the pesticide applicators left the residence (14; 15).

Previous data from animal models indicate that dichlorvos exposure may be potentially associated with prostate cancer and leukemia. A prospective cohort study of 57,311 licensed pesticide applicators began in 1993 evaluating cancer risk from dichlorvos. Less than 2% of the study population has been lost to follow up. The applicators were administered self-questionnaires, with questions such as how often they apply dichlorvos and the first time they applied dichlorvos. The study participants were broken into three groups, not exposed, low exposure, and high exposure (low exposure and high exposure were based on an algorithm that took in to account pesticide mixing, application method, equipment repair, personal protective equipment use, and cumulative exposure days). As of 2004, no correlation with lifetime use of dichlorvos and cancer risk was found (16). Dichlorvos is classified by ACGIH as A4, Not Classifiable as a Human Carcinogen because of inconsistent results from animal models (1).

These occupational/residential studies were used in the development of the aforementioned occupational exposure guidelines (MEG, TLV, PEL, and REL). The data from these studies provide human health information from actual exposure to dichlorvos showing that the occupational exposure guidelines are protective of human health. Measurable dermal and inhalation exposures occur when using dichlorvos-emitting material, which may pose a health risk, while exposures below the recommended occupational exposure guidelines should not result in health effects associated with OP exposure.

SAMPLING

The Occupational Safety and Health Administration (OSHA) Method 62 is the sampling and analysis method for dichlorvos, diazinon, chlorpyrifos, malathion, and parathion. Sampling is conducted by drawing a known volume of air through a sampling tube. The recommended air sampling volume is 480 L with a recommend air sampling rate of 1.0 L/min using personal sampling pumps. The sampler consists of a glass tube packed with the sampling media, 270-mg of cleaned (washed and soxhlet extracted with methanol and toluene) XAD-2 and 13-mm diameter glass fiber filter and has a 140-mg XAD-2 backup section, with the backup section being retained by two foam plugs (25). XAD-2 absorbent is a hydrophobic cross-linked polystyrene copolymer resin that is used to adsorb the compound of interest (30). OSHA chose the XAD-2 sampler for Method 62 because it is a common and convenient sampler of organophosphorus pesticides due to its ability to be used for collection of multiple different pesticides and to adequately collect both vapors and aerosols. Dichlorvos has 100% extraction efficiency (25) from the glass fiber filter and a 97.4% desorption efficiency (25) from the XAD-2, this is significant because there is excellent recovery of dichlorvos from this method.

Dichlorvos is desorbed with toluene and then the samples are analyzed using a Gas Chromatography (GC) - Flame Photometric Detector (FPD). The GC uses a 30 m x 0.53 mm i.d. DB-210 megabore column with a 1.0 μm film. A 1.3 μl volume of sample is injected with the injector temperature at 200 °C and held for 2 minutes. The column ramps from 150 °C to 200 °C at a rate of 16 °C/min with nitrogen flow rate of 5 mL/min and held at 200 °C for 8 minutes. The FPD requires 200 mL/min hydrogen flow, 60 mL/min oxygen flow and 30 mL/min air flow with a detector temperature of 300 °C. Dichlorvos has a retention time of about 2.0 minutes with this method.

When OSHA compared the sampling tube to an ethylene glycol bubbler using diazinon, there was no significant difference in the amount of diazinon collected between the two sampling methods, but the sampling tube method is much easier than the bubbler method and can be used for five different pesticides (25).

CHAPTER 3: DETERMINATION OF AIRBORNE CONCENTRATIONS OF DICHLORVOS OVER A RANGE OF TEMPERATURES WHEN USING COMMERCIALLY AVAILABLE PESTICIDE STRIPS IN A SIMULATED MILITARY GUARD POST

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ABSTRACT

Potential inhalational exposure to dichlorvos vapor associated with using commercially-based dichlorvos-impregnated resin strips (Nuvan Prostrips) in a simulated military guard post was evaluated. A varying number of these pesticide strips, ranging from the manufacturer's guidelines ((3)-16 gram (g) strips) up to (12)-16 g strips, were placed in a small, enclosed space similar in size to a typical military guard post and static sampling simulating personal air sampling was conducted, followed by analysis using the OSHA Method 62. Air sampling was conducted within the space at discrete temperatures in the range of 26 ˚C to 38 ˚C to determine the airborne concentration generated at each temperature setting. Airborne concentrations were compared to established military exposure guidelines (MEGs) and the 8-hour OSHA permissible exposure limit (PEL) for dichlorvos (0.99 mg/m^3). Findings indicated that exceeding the recommended number of strips as per manufacturer's recommendations for the specific workspace volume and environmental conditions produced airborne dichlorvos concentrations above established occupational standards (1.77-3.70 mg/m^3). Such

exposures may potentially lead to adverse effects, such as loss of mental and visual acuity for the guard post watch standers. However, concentrations of airborne dichlorvos generated when adhering to manufacturer's guidelines based on workspace volume resulted in levels of 0.16-0.39 mg/m^3, which were below the established occupational health limits. While dichlorvos-impregnated strips are not currently recommended for use in manned workspaces for periods > 4 hours, findings suggest that prolonged use (8 hours) of similar pesticide strips within manned spaces to kill disease-carrying insects may be a viable and safe option under similar conditions and in accordance with manufacturer's guidelines.

INTRODUCTION

Insect borne diseases remain a problem for Armies throughout the world, simultaneously decreasing operational capability and increasing the medical and logistical burden. Examples include plague, yellow fever, typhus, malaria and dengue fever, as well as a host of new and emerging infectious diseases, such as West Nile Virus (27). For example, 26 US Service Members contracted malaria in Afghanistan between January and September 2012, while an additional 91 US Service Members contracted malaria in Afghanistan in 2011 (29). Most vector borne disease threats can be mitigated through adherence to vaccination programs and prophylaxis protection for exposed personnel. The use of personal protective measures such as applying the chemical insect repellent N,N-Diethyl-meta-toluamide (DEET) to the skin, using permethrin-treated uniforms and bed nets, and employing indoor residual spraying (IRS), have demonstrated effectiveness in reducing morbidity associated with insect borne illnesses (3). Given the historical public health problems associated with deployed US forces by disease-transmitting insects, there is a need to continually seek the most efficacious measures to protect Soldiers, Sailors, Airmen, and Marines from biting insects, such as mosquitoes and sand flies.

The potential use of pesticide-impregnated strips to kill disease carrying insects in military work space settings is a potential consideration. Dichlorvos is a chemical compound often used in pesticide strips. While dichlorvos (also known as DDVP) has been effectively used against flies, mosquitoes, gnats, bedbugs, and other arthropod pests for decades in the agricultural industry, as well as in museums, trash rooms, and other settings, it has not been utilized in an occupied, military deployed work space to date. A well-known, commercially available, dichlorvos-based product is Nuvan Prostrips (AMVAC Chemical Corporation, Los Angeles, CA).

Nuvan Prostrips are resin-based strips containing 18.6% dichlorvos by weight, which are typically suspended from the overhead of an enclosed and unoccupied room. They are available in two sizes, the 16 gram (g) version is used to treat areas of 2.8-5.6 cubic meters (m^3) and the 65 g version (known as Nuvan Prostrips+) is used to treat areas of 25.5-34.0 m^3. The strips are approved for use by the US Environmental Protection Agency (EPA) to kill flies, mosquitoes, gnats, bedbugs, and other arthropod pests in spaces occupied by humans for less than four hours (2). However, no published human health exposure research could be identified by the authors regarding persons occupationally exposed for eight hours to airborne dichlorvos as a result of using dichlorvos-containing pesticide strips within enclosed spaces. The vast majority of airborne occupational exposures to dichlorvos have involved persons applying the compound as a pesticide spray in residential or commercial settings over short periods of time (2-4 h) (9; 14; 15; 18).

Recently, a senior-level scientific body within the Department of Defense (DoD) responsible for generating research-based policy and recommendations on entomological matters, has expressed an interest in commercially available, dichlorvos-containing strips for potential use as an insecticide within manned deployed guard posts (7). The application of the dichlorvos-containing strips in this manner represents an off-label use, inconsistent with the Nuvan Prostrips current manufacturer application guidelines. Currently, such strips are intended for use within uninhabited or minimally inhabited space (< 4 hours) (2). As guard post watch shifts in deployed settings may last 8 hours or more (8; 10; 17), the potential human exposure risk to airborne dichlorvos vapor emanating from the strips requires characterization, to determine if potential airborne dichlorvos exposures exceed established human health guidelines. Nuvan Prostrips were chosen as the test strip for this study.

The release of dichlorvos from the resin-based strips is affected by four main factors: the temperature, shape and size of the strip (surface area), humidity, and air movement (12; 13). Based on previous research by Gillett *et al*., temperature is the most important environmental variable impacting the release rate of dichlorvos vapor into the atmosphere (13). Given its vapor pressure at standard temperature and pressure (STP) (0.012 mm Hg), it is classified as a volatile organic compound and the partitioning of dichlorvos vapor from its liquid form into the surrounding atmosphere at increasingly higher temperatures represents a major fate of the compound. Farrell *et al*. demonstrated that the generation rate of dichlorvos from poly vinyl chloride (PVC) resin strips (the same material as in Nuvan Prostrips) doubled with every 11.1 °C increase in room temperature (12).

Both military guidelines and federal government regulatory limits have been established for dichlorvos. The military guidelines for dichlorvos exposure are published in the U.S. Army's Technical Guide-230 (TG-230). This technical document provides information on how to assess and characterize chemical exposures for deployed personnel for short- and long-term exposure timeframes. Included in the TG-230 are chemical exposure limits known as military exposure guidelines (MEGs). The TG-230 MEGs are time and severity-based exposure guidelines for chemicals in the air, soil, and water; with respective guidelines ranging in exposure duration from minutes to months and in severity, ranging in category from Negligible to Catastrophic (descriptions found in Table 3) (31). In addition, the Negligible MEG category value virtually matches the OSHA 8-hour Time-Weighted Average (TWA)- Permissible Exposure Limit (PEL) currently established for airborne exposure to dichlorvos (1.0 mg/m^3) (26).

Table 3. U.S. Army Public Health Command categorical MEGs for dichlorvos and OSHA PEL for dichlorvos (26; 31).
(Catastrophic category is for chemical warfare agents only).

	1-Hour Critical	1-Hour Marginal	1-Hour Negligible	8-Hour Negligible	OSHA PEL
Dichlorvos	72 mg/m^3	5.1 mg/m^3	0.99 mg/m^3	0.99 mg/m^3	1.0 mg/m^3
Health Effects	Threshold for life threatening effects	Performance degradation including mental, visual, dexterity, and strength	Cholinesterase inhibition	Cholinesterase inhibition	Cholinesterase inhibition

This research focused on two specific aims (Table 4): 1) measuring the airborne concentrations of dichlorvos generated at discrete temperatures within a range of temperatures (26 °C to 38 °C), when using the manufacturer-recommended number of strips based on the work space area used in the study, and 2) measuring the airborne concentration levels of dichlorvos generated at 38 °C when using up to (12)-16 g Nuvan Prostrips. Both experimental aims were conducted within an enclosed, indoor, simulated watch stander space. The purpose of using (12)-16 g Nuvan Prostrips was to represent a 'worst case' exposure scenario to watch standers, as a full pack of Nuvan Prostrips contains (12)-16 g strips. In this study, the MEG category of focus for dichlorvos was the Negligible category (description found in Table 3), as concentrations levels exceeding the Negligible category may lead to serious and debilitating health effects that may degrade a watch stander's ability to see and respond to any physical security threats in their area of responsibility. The airborne concentrations determined during these two primary experiments were then compared to the 1-hour and 8-hour Negligible MEGs to determine if the levels measured were consistent with those known to cause adverse health effects in humans.

Table 4. Research Aims

Experiment	Description
1. Evaluate Effects of Increased Temperature on Airborne Concentration when using Constant Mass of Dichlorvos	(3)-16 g Nuvan Prostrips (Manufacturer's recommendation based on space size) were placed in enclosed space with temperatures of 26 °C, 28 °C, 35 °C, 38 °C, respectively
2. Evaluate Effects of Increased Mass of Dichlorvos on Airborne Concentration when a Single, Discrete, High Temperature used	At 38 °C, increasing masses of Nuvan Prostrips (48 g, 65 g, 96 g, 192 g) were used in the enclosed space

MATERIALS AND METHODS

The concentration of airborne dichlorvos released from the Nuvan Prostrips was determined using an established OSHA air sampling method (OSHA Method 62) under controlled conditions. Experiments were conducted within an empty, temperature-controlled experimental room within a professional building. This space was chosen because it was similar in size to a possible guard post used in U.S. forward deployed operations, while providing the means to control the temperature and airflow during the experiment. The dimension of the space was 2.31 m (length) x 2.26 m (width) x 2.44 m (height), providing a total volume of 12.7 m^3. The simulated environment facilitated the understanding of the rate of release of dichlorvos from the strips as a function of temperature, especially as increasing masses of dichlorvos strips were employed. Over the course of this study, the experimental room temperature was maintained at discrete, stable temperatures between 26 °C and 38 °C, as indicated in Table 3. While the humidity levels were measured at several time intervals during the experiments and were found to be relatively stable, there was no ability for the research team to control humidity, so the potential effects of this variable were not evaluated for the purposes of this study. Additionally, as initial supply and exhaust flow within the space was considered too high for the experimental design, the supply and exhaust ventilation were obstructed to limit airflow to ≤9 air changes per hour (ACH). The ventilation was measured using a properly calibrated balometer (Alnor Balometer Jr, TSI, Shoreview, MN). Given the potential for wide variation in construction of military watch stander guard posts and ambient weather conditions at deployed sites, in which the use of Nuvan Prostrips could be employed as an insecticide for disease-carrying insects, it is a great challenge to provide more than a best guess of "average" airflow within and through a particular guard post; therefore the air change rate produced in the simulated space was considered to be acceptable for this study.

Temperature and relative humidity (RH) measurements were taken every five minutes throughout the duration of all of the experiments using the HOBO U14 data logger (Onset Computer Corporation, Inc, Bourne, MA). All 1-hour and 8-hour samples were taken in triplicate for each experiment, using personal air sampling pumps (SKC AirChek XR5000, Eighty Four, PA) and sampling media (SKC OVS-XAD2 air sampling tubes, Eighty Four, PA) set in accordance with OSHA Method 62 (25). Sampling pump flow rates were set to 1 liter per minute (LPM) and calibrated before and after experiments using a Gilian Gilibrator 2 calibrator (Synsidyne, St. Petersburg, FL). Six air sampling pumps were used concurrently (arranged alternately, side-by-side) during each different temperature and mass experiment to collect triplicate samples for both 1-hour and 8-hour dichlorvos samples. Six air sampling stands were used to secure the air sampling media in the breathing zone (1.4 m high), and two music stands were used as a platform for the air sampling pumps (Figure 3). Prior to initial startup of the air sampling pumps, the door to the experimental room was briefly opened and closed to allow for the investigator to enter the room and then again to allow the quick exit from the space after turning all of the pumps on. After passage of one hour, the investigator once again entered the experimental room to stop and remove the 1-hour air sampling pumps and then the investigator exited the space. After seven additional hours, the room was again entered to allow the investigator to enter the room and turn off the remaining air sampling pumps.

Figure 3: Equipment setup with in the experimental space.
Pictured is the (1)-65 g Nuvan Prostrip+ experiment. (**A**– HOBO Thermometer/Humidity Meter, **B** – Nuvan Prostrip+, **C –** Sampling Media, **D –** Sampling Stand, **E** – Personal Air Sampling Pump)

On day one, (3)-16 g Nuvan Prostrips (48 g total weight, 8.9 g dichlorvos by weight) were suspended 0.3 m from the ceiling using waxed dental floss (Figure 4) and allowed to equilibrate at 26 °C. The temperature was adjusted to 28 °C after the completion of the 26 °C sampling; subsequently, air sampling was conducted at 28 °C. Likewise, the temperature was adjusted to 35 °C after sampling at 28 °C and air sampling was conducted at 35 °C. After 35 °C sampling was completed, the temperature was then adjusted to 38 °C and sampling was conducted on at 38 °C. For all experiments the strips were allowed to equilibrate for a minimum of 18 hours at each temperature setting prior to sampling occurring.

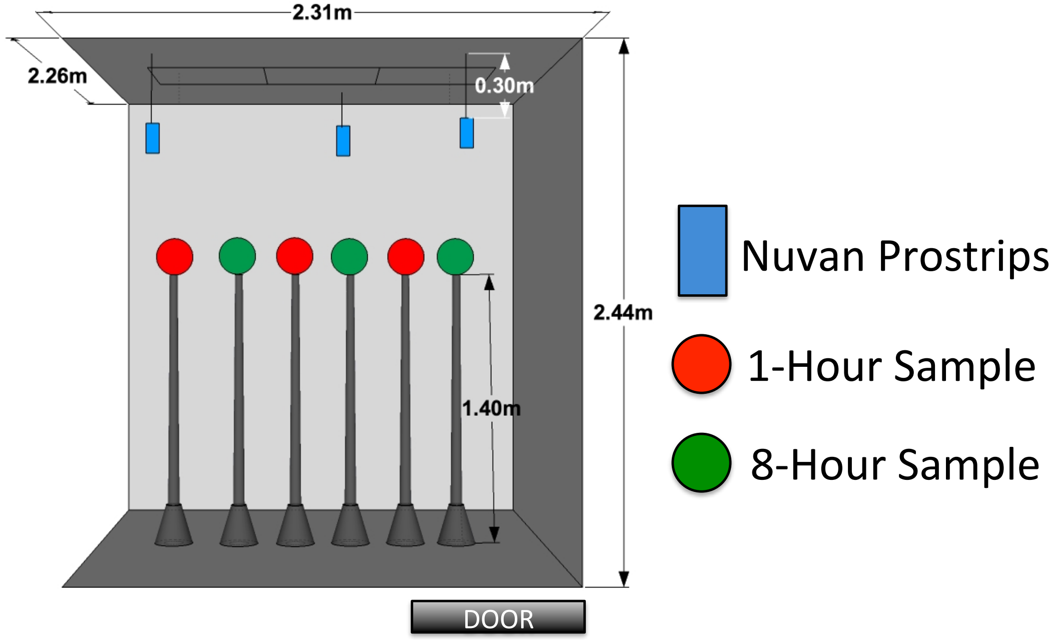

Figure 4: Side view of the experimental room set up, 48 g Nuvan Prostrips (3) – 16 g Nuvan Prostrips are suspended 0.3 m from the ceiling, air sampling pumps were placed on music stands next to the 1.4 m high air sampling stands where the 1-hour and 8-hour samples alternately placed. The 1-hour samples were removed after the first hour.

For the increasing mass experiments, the total mass of dichlorvos was increased by the use of additional Nuvan Prostrips (48 g, 65 g, 96 g, and 192 g respectively) within the enclosed space. These experiments were intended to characterize the respective airborne concentrations of dichlorvos as temperatures increased, but also to demonstrate a 'worst-case' scenario if eventually the whole package of Nuvan Prostrips (192 g) were to be used by the watch standers at a given time if performing their duties at a temperature matching the highest temperature achievable for the experimental space.

With the room at 38 °C, separate experiments were conducted with 48 g total weight of Nuvan Prostrips (8.9 g dichlorvos by weight; Figure 4), 65 g total (12.1 g dichlorvos by weight; Figure 5), 96 g total (17.9 g dichlorvos by weight; Figure 6), and 192 g total (35.7 g dichlorvos by weight; Figure 7) with a minimum of 18 hours equilibration time between each experiments.

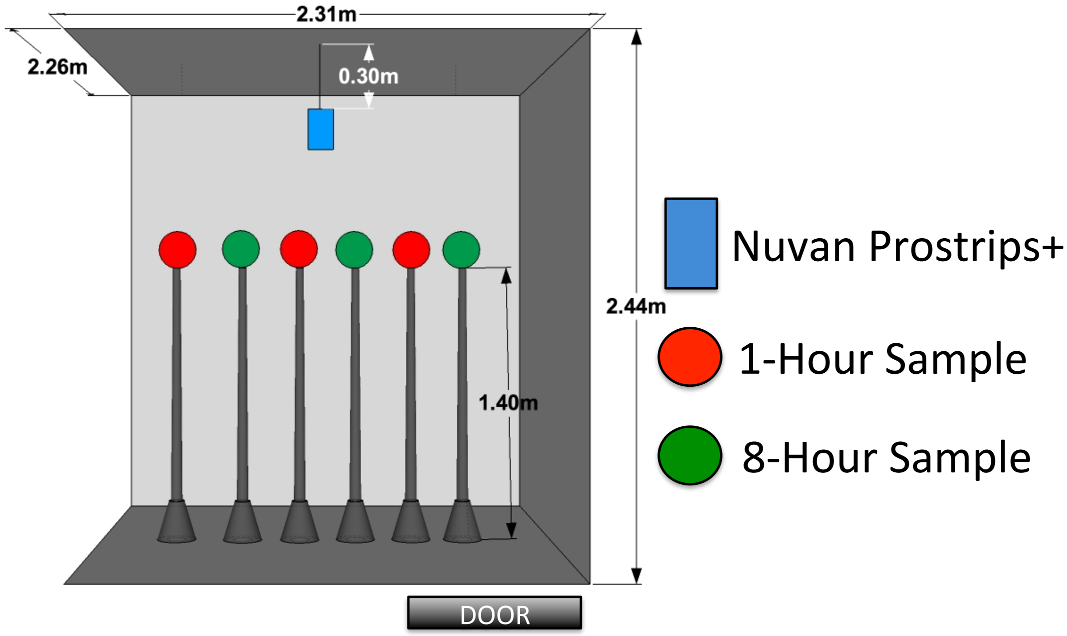

Figure 5: Side view of the experimental room, 65 g Nuvan Prostrips+
(1) - 65 g Nuvan Prostrips+ is suspended 0.3 m from the ceiling, air sampling pumps were placed on music stands next to the 1.4 m high air sampling stands where the 1-hour and 8-hour samples were alternately placed. The 1-hour samples were removed after the first hour.

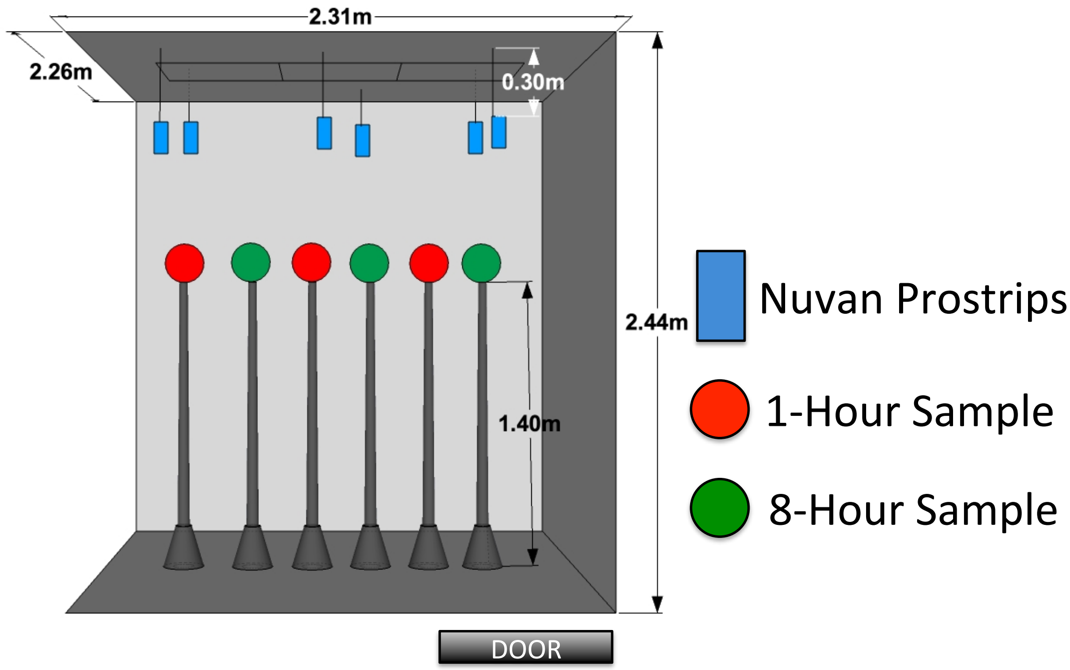

Figure 6: Side view of the experimental room, 96 g Nuvan Prostrips (6) –16 g Nuvan Prostrips are suspended 0.3 m from the ceiling, air sampling pumps were placed on music stands next to the 1.4 m high air sampling stands where the 1-hour and 8-hour samples were alternately placed. The 1-hour samples were removed after the first hour.

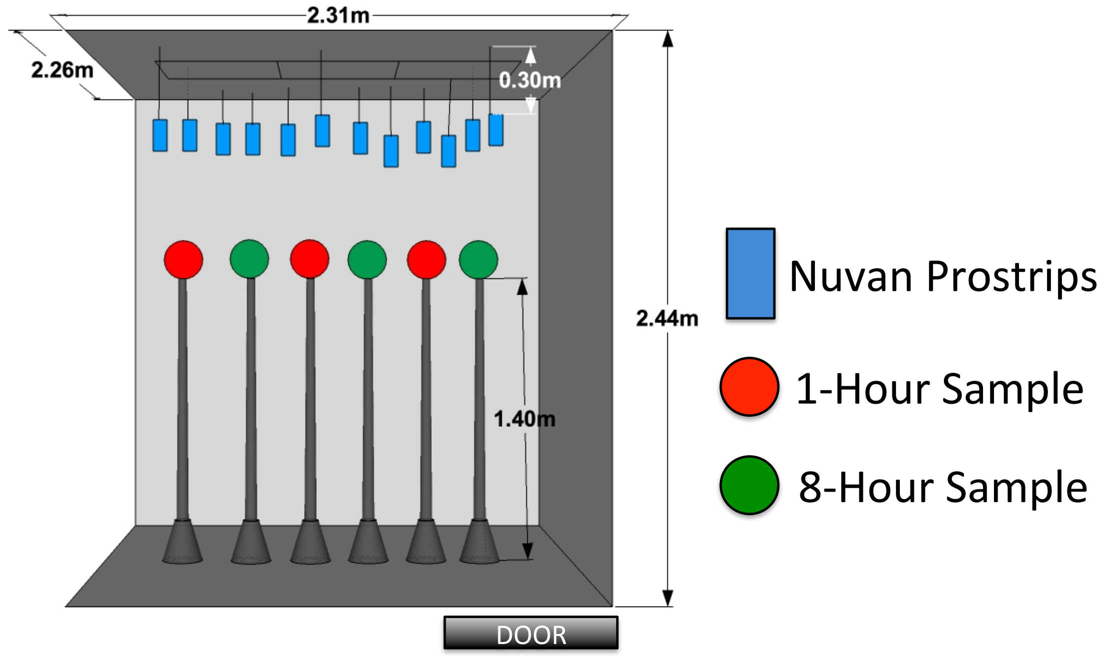

Figure 7: Side view of the experimental room, 192 g Nuvan Prostrips (12) -16 g Nuvan Prostrips are suspended 0.3 m from the ceiling, air sampling pumps were placed on music stands next to the 1.4 m high air sampling stands where the 1-hour and 8-hour samples were alternately placed. The 1-hour samples were removed after the first hour.

Sample Analysis

All samples were refrigerated immediately after collection and subsequently sent to the Navy and Marine Corps Consolidated Industrial Hygiene Laboratory Detachment Norfolk (CIHL) for analysis within 10 days of collection. The CIHL used a modified version of OSHA method 62 for the analysis, which consisted of the Gas Chromatography (GC)-Electron Capture Detector (ECD) rather than GC-Flame Photometric Detector (FPD).

Statistical Analysis

The laboratory results for each sample were statistically analyzed using three methods: graphically, relative standard deviations (RSD), and one-way ANOVA. Each data point for all experiments was calculated as the average from triplicate sampling for the one-way ANOVA. The data for the respective samples was graphed in scatterplots and a best-fit line was applied with R^2 values calculated to visualize any trends. RSDs were calculated for each data point to assess the variation within the triplicate sample. A one-way ANOVA (normal distribution, and equal variance assumed) was performed to compare average concentrations among the sample groups.

RESULTS AND DISCUSSION

The 1-hour data (Table 5) obtained from the discrete temperature points over a range of increasing temperatures was observed to have a low R^2 value (Figure 8), which possibly suggests that the airborne concentrations of dichlorvos may been affected by the entering and exiting of the small experimental space to activate and deactivate the pumps. This perturbation of the airborne environment may have led to a reduced airborne concentration due to equilibrium changes. The p-values (Table 5) for one-way ANOVA for these values indicate that they do not significantly differ from one another.

Table 5. Increasing Temperature: 1-Hour Results
Each of the temperatures tested resulted in values below the 1-hour Negligible MEG. The one-way ANOVA showed that all of the groups were not significantly ($p=0.813$ for 26 °C and 28 °C, $p=0.678$ for 26 °C and 35 °C, $p=0.154$ for 26 °C and 38 °C, $p=0.994$ for 28 °C and 35 °C, $p=0.471$ for 28 °C and 38 °C, $p=0.607$ for 35 °C and 38 °C) different from one another.

Temperature (°C)	% Relative Humidity	MEG (mg/m^3)	Concentration (mg/m^3)
26	17.6	0.99	**0.16**
28	23.8	0.99	**0.18**
35	12.6	0.99	**0.19**
38	9.2	0.99	**0.22**

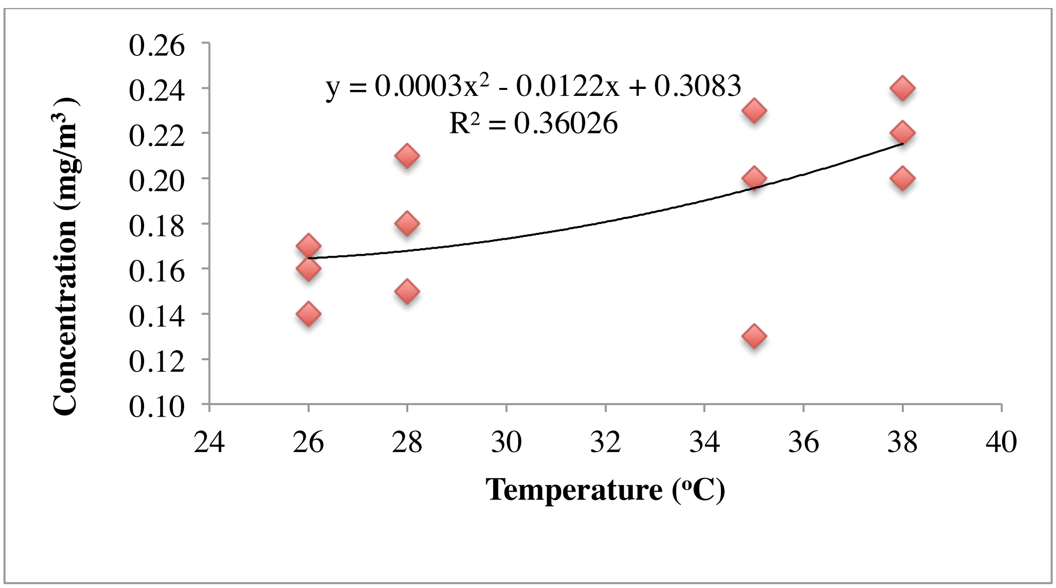

Figure 8: Increasing Temperature: 1-Hour Results
Each datapoint on the scatterplot represents a single sample. The RSDs for the triplicate groups were 2% at 25 °C, 3% at 28 °C, 5% at 35 °C, and 2% at 38 °C.

The 8-hour samples (Table 6) from the increasing temperature experiment demonstrated a high R^2 value (Figure 9) suggesting that the increases in airborne dichlorvos concentration (in mg/m^3) followed increases in temperature (in °C) in a predictive quadratic manner, such that the best-fit line is a quadratic equation. The p-values (Table 6) from the one-way ANOVA indicate that all of the samples were significantly different from one another except for the 26 °C and 28 °C (p=0.995).

Table 6: Increasing Temperature: 8-Hour Results
Each of the temperatures tested resulted in values below the 8-hour Negligible MEG. The one-way ANOVA showed that all of the groups were significantly different except for 26 °C and 28 °C (p=0.995 for 26 °C and 28 °C, p=0.001 for 26 °C and 35 °C, p=0.000 for 26 °C and 38 °C, p=0.002 for 28 °C and 35 °C, p=0.000 for 28 °C and 38 °C, p=0.006 for 35 °C and 38 °C).

Temperature (°C)	**% Relative Humidity**	**MEG (mg/m^3)**	**Concentration (mg/m^3)**
26	16.4	0.99	**0.24**
28	23.0	0.99	**0.25**
35	11.6	0.99	**0.33**
38	8.7	0.99	**0.39**

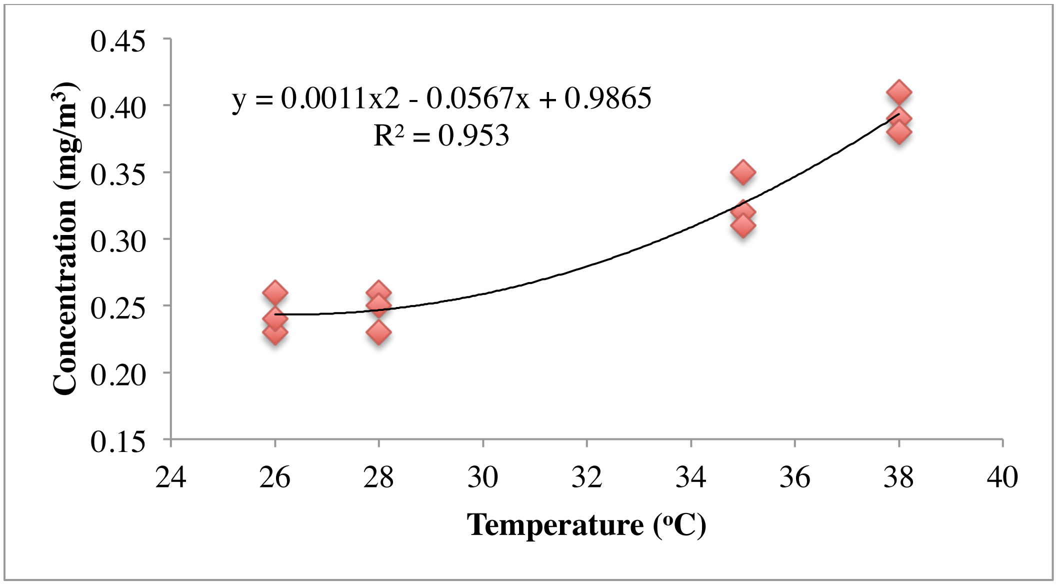

Figure 9: Increasing Temperature: 8-Hour Results
Each datapoint on the scatterplot represents a single sample. The RSDs for the triplicate groups were 2% for all temperatures.

The data from 1-hour increasing mass experiment (Table 7) displayed a high R^2 value (Figure 10), suggesting that the increases in airborne dichlorvos concentration (in mg/m^3) followed increases in dichlorvos mass (in g) in a predictive quadratic manner, such that the best-fit line is a quadratic equation. The best-fit line also appeared to be approaching linearity at a point between 90 g and 192 g, suggesting that saturation of dichlorvos in the air may have been occurring. The p-values (Table 7) from the one-way ANOVA indicate that all of the samples were significantly different from one another.

Table 7: Increasing Mass: 1-Hour Results
At 38 ˚C, total Nuvan Prostrip masses of 96 g and greater (17.9 g dichlorvos by weight or more) generated airborne dichlorvos concentrations greater than the 1-hour Airborne Negligible MEG. The one-way ANOVA showed that samples for each mass were significantly different from one another ($p=0.009$ for 48 g and 65 g, $p=0.000$ for 48 g and 96 g, $p=0.000$ for 48 g and 192 g, $p=0.000$ for 65 g and 96 g, $p=0.000$ for 65 g and 192 g, $p=0.000$ for 96 g and 192 g).

Mass (g)	Temp/%RH	MEG (mg/m^3)	Concentration (mg/m^3)
48	38.1 °C/9.2	0.99	**0.22**
65	37.8 °C/4.6	0.99	**0.65**
96	37.8 °C/5.0	0.99	**1.77**
192	38.1 °C/7.6	0.99	**3.23**

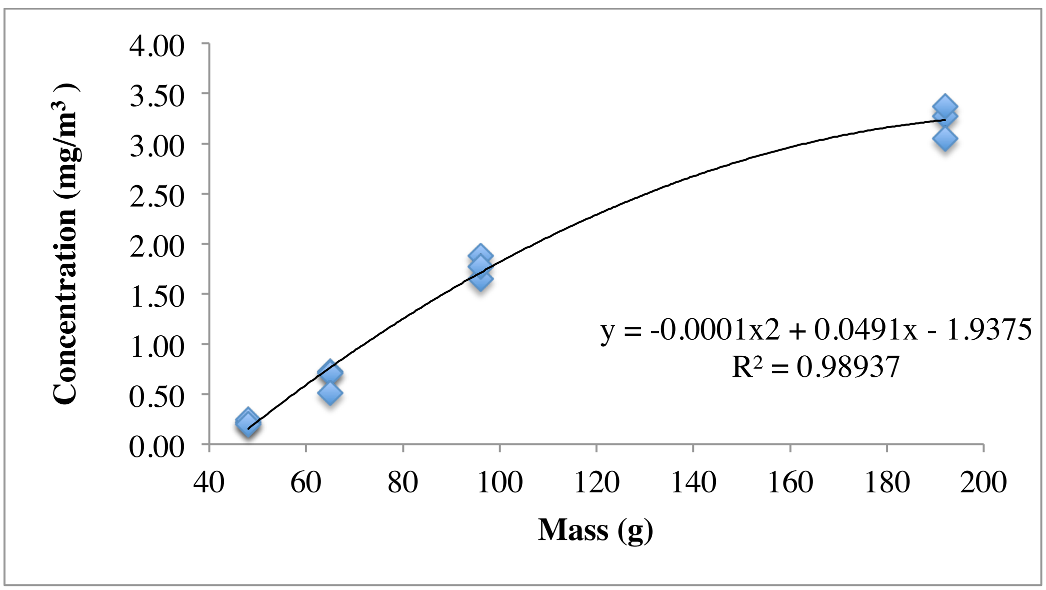

Figure 10: Increasing Mass: 1-Hour Results
Each datapoint on the scatterplot represents a single sample (3 datapoints per mass represented). The RSDs for the triplicate groups were 2% for 48 g, 12% for 65 g, 12% for 96 g, and 16% for 192 g.

The results of the 8-hour time-weighted average samples when using increasing masses of dichlorvos at 38 °C (Table 8) demonstrated a high R^2 value (Figure 11), suggesting that the increases in airborne dichlorvos concentration (in mg/m^3) followed increases in dichlorvos mass (in g) in a predictive quadratic manner, such that the best-fit line is a quadratic equation. The best-fit line also appears to be approaching linearity at a point between 90 g and 192 g, suggesting that saturation of dichlorvos in the air may have been occurring. The p-values (Table 8) from the one-way ANOVA indicated that the sample results for each respective datapoint were significantly different from one another.

In this 'worst case' scenario, where an entire package of Nuvan Prostrips were employed in a simulated guard post, the 8-hour Negligible MEG was exceeded by almost four times. This airborne concentration (or likely higher concentrations, given higher ambient temperatures) may be possible without appropriate oversight and education of watch standers with access to dichlorvos-impregnated strips for insecticidal means. It would be expected that health effects associated with the Negligble MEG (Cholinesterase inhibition) would be seen in the watch standers, possibly impacting their ability to fully perform their duties of keeping the base secure. Additionally, the adverse health effects associated with the Marginal MEG (increasingly greater performance degradation including mental, visual, dexterity, and strength) would most likely not be seen in majority of the population at this exposure level, it might be possible for sensitive/susceptible individuals to develop symptoms of overexposure.

Table 8: Increasing Mass: 8-Hour Results
At 38 ˚C, total Nuvan Prostrip masses of 96 g and greater (17.9 g dichlorvos by weight or more) generated airborne dichlorvos concentrations greater above the 8-hour Negligible MEG. The one-way ANOVA showed that samples for each mass were significantly different from one another ($p=0.011$ for 48 g and 65 g, $p=0.000$ for 48 g and 96 g, $p=0.000$ for 48 g and 192 g, $p=0.000$ for 65 g and 96 g, $p=0.000$ for 65 g and 192 g, $p=0.000$ for 96 g and 192 g).

Mass (g)	Temp/% RH	MEG (mg/m^3)	Concentration (mg/m^3)
48	38.4 °C/8.7	0.99	**0.39**
65	38.0 °C/4.3	0.99	**0.79**
96	38.2 °C/4.5	0.99	**2.11**
192	38.3 °C/6.3	0.99	**3.70**

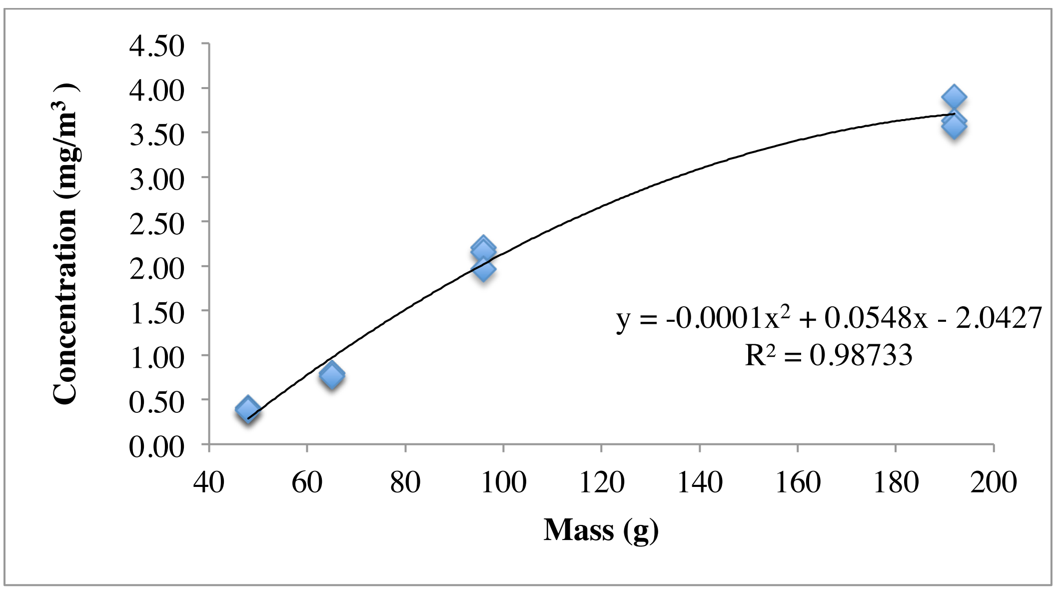

Figure 11: Increasing Mass: 8-Hour Results
Each datapoint on the scatterplot represents a single sample (3 datapoints per mass represented). The RSDs for the triplicate groups were 2% for 48 g, 2% for 65 g, 13% for 96 g, and 18% for 192 g.

CONCLUSIONS/FUTURE STUDIES

This study focused on the potential use of Nuvan Prostrips in a simulated guard post, which would allow for more options of pesticides to keep deployed service members protected from disease transmitting insects, supplementing the DEET and permethrin treated uniforms. The results of this study suggest that if dichlorvos-impregnated strips are used in amounts greater than 65 g (>12.1 g dichlorvos) when working in temperatures of 38 °C or greater, the potential exists to reach airborne concentrations greater than the established and recommended occupational health standards (OSHA 8-hour TWA and USAPHC Negligible MEGs), thus adversely affecting watch standers' health and/or ability to function effectively. However, under environmental conditions similar to those used in this research and when following the manufacturer's recommended application instructions, use of dichlorvos-impregnated pesticide strips (such as Nuvan Prostrips) are not expected to produce airborne concentrations above the 1-hour and 8-hour Negligible MEGs/OSHA 8-hour PEL. These results suggest that future use of dichlorvos-impregnated strips within military guard posts, some of which are established in areas of high endemic insect borne disease, may be an effective choice for an insecticide use while still protective of human health.

The potential impact from the opening and closure of the door, which occurred during each experiment to place and remove the air sampling pumps, may have been a factor during the experiments. The results suggest that changes in airflow, even if slight to moderate, can significantly impact the airborne concentration of dichlorvos in the surrounding workspace atmosphere. Future studies should consider employing remote start air sampling pumps to avoid this potential confounder for airborne concentration values.

As discussed, the indoor experimental space was limited to a maximum temperature 38 °C, and thus was not able to reach the extreme temperatures (45 ˚C – 50 ˚C) which may be found in deployed military settings. Future experiments utilizing either an indoor space with the ability to heat similar to the extreme temperatures, and/or an outdoor space in summertime conditions, similar to those found in military deployed settings, should be investigated. This will allow for a more complete picture with regard possible temperatures that may be experienced to be developed.

Additionally, incorporating a multi-disciplinary approach could be employed between industrial hygienists and entomologists to correlate airborne concentrations of dichlorvos generated when using various masses over a range of temperatures with entomological-based insect behavior observations when insects are exposed to these different concentrations. This approach should be conducted in laboratory and field environments to determine if insect observations from the laboratory can be correlated to the field setting. Using this approach could determine the most efficacious insecticidal concentrations for disease carrying vectors while concurrently determining if these effective insecticidal levels exceed occupational health limits protective of human health.

ACKNOWLEDGEMENTS

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CHAPTER 4: FUTURE RESEARCH

A comprehensive model for risk assessment is needed to link all of the components that are necessary to make sound risk management decisions. This model should take a multi-disciplinary approach that utilizes industrial hygiene, environmental chemistry, entomology, human health, and risk assessment disciplines. Such an approach would allow for a more complete picture to be created prior to making any decisions.

Further industrial hygiene research including fieldwork is necessary to determine if the results seen in this research translate to a real world setting. This research should utilize both commercial and makeshift guard posts in different environmental and geographical conditions because it is difficult to predict where the next conflict or humanitarian mission will be. Supplemental laboratory work could use a delay start on the air sampling pumps to allow concentrations to reach equilibrium before start, have a range of air changes per hour, and also ensure that the airflow is measured more frequently. Additionally, investigation into the time requirement for Nuvan Prostrips to reach equilibrium and the atmospheric half-life of dichlorvos under the various conditions presented by guard post environments should be conducted. This research should focus on the volatilization rate and general ventilation to determine if what was found in the room is what was predicted based on the model. To determine the impact of surface area on airborne concentrations of dichlorvos, a study involving the use of comparable masses but different surface areas (for example, using (4) – 16 g strips and (1) – 65 g strip should be investigated.

Environmental chemistry research should be conducted to determine the degree to which dichlorvos may accumulate on the walls and ceilings of earthen guard posts over time. If significant dichlorvos accumulation occurs, further research should determine if it re-volatilizes, contributing to higher airborne concentrations of dichlorvos than expected or a more rapid equilibrium. Additionally, other environmental fates of dichlorvos should be investigated to see if there is a large impact to the surrounding environment in which these strips may be used. Such experiments can determine if there is a concentration build-up and the proper schedule of strip replacement to support continued efficacy.

Continuing with this multi-disciplinary approach, entomological research should be considered. Effectiveness studies of Nuvan Prostrips at various concentrations appropriate for guard post use could determine the effectiveness for killing the insects that are the disease vectors. This research should concentrate on disease vectors of interest worldwide as insect species vary throughout the world. Additionally, correlations between airborne concentrations when using various masses over a range of temperatures with entomological-based insect behavior observations should be developed. This could also be useful in determining if greater or lesser masses of Nuvan Prostrips are required for the unique environment of guard posts. Additionally, using this multi-disciplinary approach could likely assist in determining the most efficacious concentrations while concurrently determining if these effective insecticidal levels exceed occupational health limits protective of human health.

More human health studies are needed to fully understand what all of the health effects would be for people exposed to airborne dichlorvos in such a fashion. Thus far there has been very little work done to characterize human responses to airborne dichlorvos other than cholinesterase inhibition. Future studies should focus on ocular, mental and physical responses at exposure levels of the occupational health guidelines. Additionally, a study of the use of Nuvan Prostrips in conjunction with wear of permethrin treated uniforms may be advisable to ensure that service members are not adversely impacted by the combination of these two pesticides.

In order to round out the multi-disciplinary approach, as this research solely considered airborne dichlorvos concentrations, other exposure routes should be researched. Specific to the 8-hour watch standers, who cannot leave the guard post, other exposure routes such as dermal and ingestion should be considered. In addition to dermal absorption from airborne dichlorvos, sampling should also focus on if surface deposition occurs from airborne dichlorvos followed by transfer to dermal tissue. According to the Nuvan Prostrip label, strips should not be used in food preparation or consumption areas (2). Watch standers, however, have the potential for expose while eating, drinking, and in some instances smoking. It is important to study these additional exposure pathways to fully assess the risk to watch standers.

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