CHARACTERIZATION OF ORGANIC SOLVENT EXPOSURE DURING SHIPBOARD OPERATIONS ONBOARD A U.S. NAVY AIRCRAFT CARRIER

by

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Thesis submitted to the Faculty of the
Preventive Medicine and Biostatistics Graduate Program
Uniformed Services University of the Health Sciences
In partial fulfillment of the requirements for the degree of
Master of Science in Public Health 2017

UNIFORMED SERVICES UNIVERSITY, SCHOOL OF MEDICINE GRADUATE PROGRAMS
Graduate Education Office (A 1045), 4301 Jones Bridge Road, Bethesda, MD 20814

March 1, 2017

MEMORANDUM FOR: **MARY T. BRUEGGEMEYER, MD**
MARIA K. MAJAR, MS
NICHOLAS C. SCHAAL, PhD

SUBJECT: Appointment to the Final Master's Examination Committee for Judy S. Kirnon

In accordance with the School of Medicine Graduate Program Guidelines, you are formally appointed to the Final Examination Committee of Judy S. Kirnon, Master of Science in Public Health student in the Department of Preventive Medicine & Biostatistics.

This Committee will evaluate the scope and qualities of the student's Dissertation and certify the document's acceptability.

In addition, the Committee will conduct an Oral Examination of the student's scientific knowledge, as well as her knowledge/ understanding of her thesis research project and Dissertation. This Examination constitutes the Private Defense.

The Private Defense for Judy S. Kirnon will take place on Monday, March 20, 2017 at 1:30 PM, in AFRRI OEHS Conference Room 3176H.

Dr. Mary T. Brueggemeyer is appointed Chair of the Examination Committee. Dr. Brueggemeyer will oversee the Examination. Passage of the Private Defense will be by majority vote. If corrections to the Dissertation are needed, the Chair may oversee this process and sign-off after the corrections are made.

The Committee Chair should return the signed Final Examination/Private Defense Form and the Dissertation Approval Form to the Graduate Education Office as soon as each Form is completely signed.

GEO thanks you in advance for your participation in the SOM Graduate Program process.

Gregory P Mueller

Gregory P. Mueller, Ph.D.
Associate Dean for Graduate Education

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FINAL EXAMINATION/ PRIVATE DEFENSE FOR THE DEGREE OF MASTER OF SCIENCE IN PUBLIC HEALTH IN THE DEPARTMENT OF PREVENTIVE MEDICINE AND BIOSTATISTICS

Name of Student: Judy S. Kirnon

Date of Examination: March 20, 2017

Time: 1:30 PM

Place: AFRRI OEHS Conference Room 3176H

DECISION OF EXAMINATION COMMITTEE MEMBERS:

	PASS	FAIL
Mary T. Brueggemeyer, MD, MPH, Col DEPARTMENT OF PREVENTIVE MEDICINE & BIOSTATISTICS Committee Chair	X	
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DISSERTATION APPROVAL FOR THE MASTER IN SCIENCE IN PUBLIC HEALTH DISSERTATION IN THE DEPARTMENT OF PREVENTIVE MEDICINE AND BIOSTATISTICS

Title of Thesis: "Characterization of Organic Solvent Exposure during Shipboard Operations Onboard a US Navy Aircraft Carrier"

Name of Candidate: Judy S. Kirnon
Master of Science in Public Health Degree
March 20, 2017

THESIS AND ABSTRACT APPROVED:

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CPT Judy S. Kirnon

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ABSTRACT

Characterization of Organic Solvent Exposure During Shipboard Operations Onboard a U.S. Navy Aircraft Carrier:

CPT Judy S. Kirnon, Master of Science in Public Health, 2017

Thesis directed by: Captain Maria K. Majar, MSC, USN, CIH, CSP, Assistant Professor, Department of Preventive Medicine and Biostatistics.

Ethylbenzene, toluene, and xylene have been described as organic solvents that have potential ototoxic effects especially in combination with noise exposure. U.S. Navy personnel are often exposed to occupational hazards from various organic solvents and continuous noise while assigned to aircraft carriers. There is limited available data regarding organic solvent inhalation exposures to Navy personnel during shipboard operations. A total of 80 personal breathing zone samples were collected onboard a U.S. Navy aircraft carrier using a 3M™ Organic Vapor Diffusion Monitor to estimate the concentration levels of ethylbenzene, toluene, and xylene during job processes such as hazardous material (HAZMAT) issue, painting, fuel analysis, fuel pump maintenance, and oil testing. Over 90% of the sample results were below the laboratory limit of quantitation (LOQ) which required censored data analysis (CDA) for data evaluation. Additionally, 16 of 240 sample results were above the LOQ.

All sample results were less than 10% of an adjusted 12-hr American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Value (TLV®). Data analysis showed that there was a statistically significant difference in toluene among HAZMAT exposure group as compared to the other homogenous exposure groups ($p = 0.006$). Organic solvent concentrations found during this study appear to be minimal compared to solvent concentrations that have been found to elicit adverse audiological outcomes in past studies. However, future research should aim to characterize exposure to other chemicals that may damage hearing over the course of the ship's life cycle for a more comprehensive assessment to personnel assigned to aircraft carriers.

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Background

Occupational hazards in an industrial or manufacturing work environment involve a combination of physical and chemical exposures. Although noise exposure has been considered the main factor in occupational hearing loss, organic solvent exposure has been linked to hearing loss as well [1]. Organic solvents, like ethyl benzene, toluene, and xylene are described as ototoxic chemicals and are also components in jet fuel, cleaning solvents, degreasers, adhesive resins, paint, paint primers and thinners. Studies have indicated that some organic chemicals can alter the structure and function of the inner ear and as well as central auditory nerves [2]. Several animal and human studies have indicated that exposure to organic solvent substances can have an additive effect or act synergistically with noise to increase the risk of noise-induced hearing loss (NIHL). These studies also indicate that at sufficiently high concentrations some organic chemicals can affect hearing despite noise exposure levels ranging between 80-90 dB(A) [3]. In an industrial environment, noise and mixed solvent exposure is common and usually at levels near or below occupational exposure limit levels [4]. Several studies have also shown that hearing loss occurs after prolonged exposure to both hazard. These conditions are similar in a military occupational environment where the combination of chemical and physical hazards exist for service members throughout their military career. On an aircraft carrier, U.S. Navy personnel are continuously exposed to a steady-state noise environment and to various organic solvents used in ship maintenance and flight deck operations increasing the risk of hearing loss. Although regulatory and recommended exposure levels have not yet been established to control for ototoxic exposure to various chemicals in the workplace, this study aims to characterize the potential inhalation exposure to Navy personnel by sampling ambient air concentrations of ethylbenzene, toluene, and xylene on an aircraft carrier during shipboard operations.

Regulatory Recommendation

Fuels, organic solvents, some asphyxiants, and certain heavy metal compounds have been linked to ototoxic effects [5]. Several studies indicate an additive or synergistic effect on hearing from organic chemicals when combined with noise exposure [2, 6, 7]. Occupational Health and Safety Administration (OSHA) regulation 1910.95 states that workers can be exposed to 90 dB(A) for an 8-hr TWA or up to 85 dB (A) for a 16-hr work day [8]. However, the American Conference of Governmental Industrial Hygienists (ACGIH) TLV® recommends lower noise levels not to exceed 85 dB(A) for an 8-hr TWA or 83 dB(A) for a 12-hr TWA in order to minimize adverse effects on hearing and the ability to understand normal speech [9]. Sound pressure measurements taken on the A-weighted scale simulates the sensitivity of sound to the human ear and correlates to hearing loss from continuous noise exposure [10]. Studies by Morata et al. and Sliwinska-Kowalska et al. have shown that moderate exposure to mixed solvents, even with noise levels below 85dB(A), can lead to an increased risk of hearing loss [4, 6].

The ACGIH TLV® Chemical Substance Documentation for mixed and single isomers of xylene recommends that exposure not exceed 100 ppm (434 mg/m^3) to minimize irritant effects and significantly reduce narcosis or chronic injuries [11]. The TLV-TWA for toluene (75 mg/m^3) and ethylbenzene (87 mg/m^3) is 20 ppm. Toluene TLV® is based on reducing subclinical effects in vision, central nervous system, and preventing spontaneous abortion in females [12]. However, neither toluene nor xylene chemical documentations address the ototoxic effects previously evaluated by other animal and human studies. Notably, the exposure limits for ethylbenzene is intended to minimize the risk of irritation, organ damage, and hearing loss [13].

Absorption Distribution Metabolism and Excretion

Ethylbenzene, toluene, and xylene are single-ring aromatic hydrocarbon compounds and classified as alkyl derivatives of benzenes. Organic, or alkyl benzene chemicals are commonly used as industrial solvents to dissolve other organic compounds due to a low evaporation rate and high lipid solubility. Organic solvents can irritate and damage the skin, eyes, respiratory tract, and cause narcosis of the central and peripheral nervous system [14]. These compounds are easily absorbed across the alveolar-capillary membrane making inhalation the primary route of exposure [14]. Pulmonary retention time ranges as low as 45% for ethylbenzene to 60% for xylene, and as high as 96% for toluene [15]. At various levels of physical labor, pulmonary uptake can increase by a factor of 2-3 times more [14]. Absorption can also occur through ingestion and dermal contact but at a slower rate of absorption than inhalation. A small percentage of the compound is exhaled unchanged. Alkyl benzenes are rapidly absorbed into the vascular system, distributed to adipose tissue and further metabolized in the liver [15]. Metabolism of the alkyl benzene involves oxidation of the side chain on the benzene ring by cytochrome P450, alcohol dehydrogenase, and aldehyde dehydrogenase creating an acid compound derivative. The acid derivative is further conjugated with a glycine enzyme forming urinary metabolites. Figure 1 illustrates an example of an alkyl benzene, such as toluene, as it metabolizes into different intermediates to form metabolites [15].

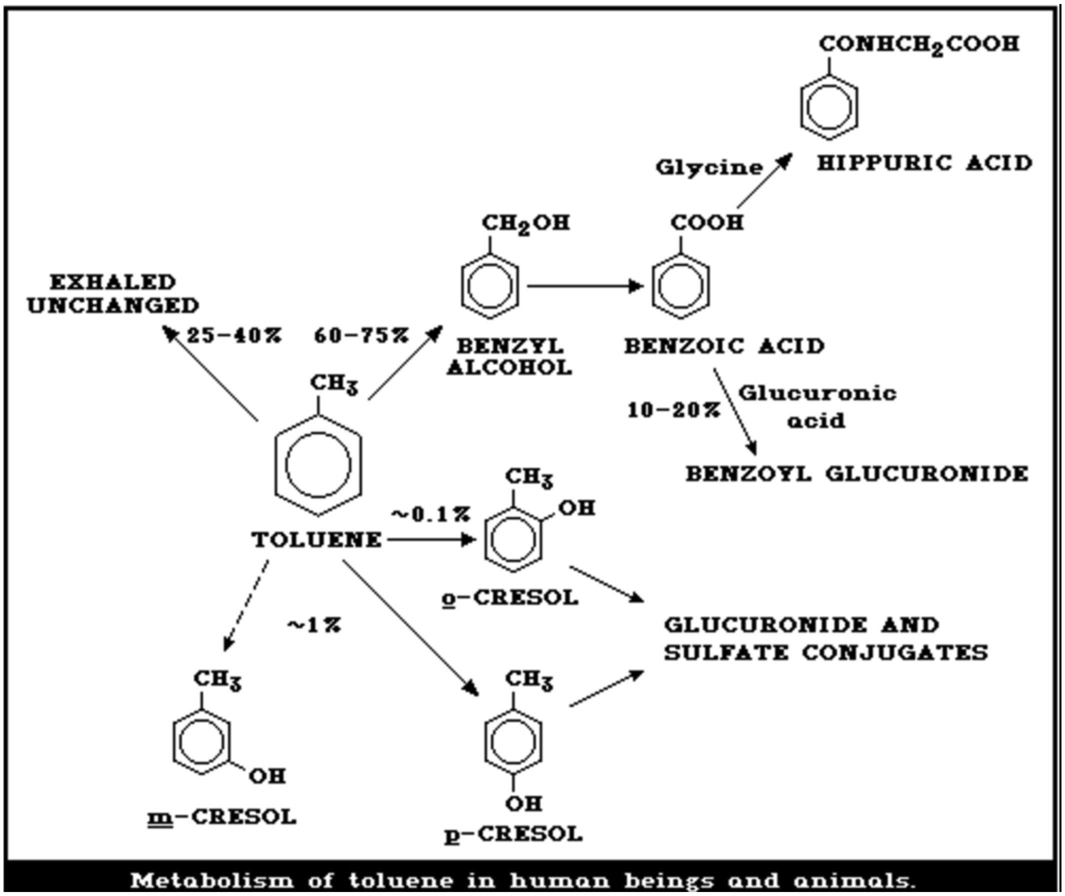


Figure 1. Metabolism of Toluene [16]

The ACGIH Biological Exposure Indices (BEI®) guidelines represent the levels of biological determinants that can be expected when workers are exposed to airborne concentrations comparable to the TLV® [9]. However, factors such as physiological disposition, workplace conditions, and use of personal protective equipment may influence the variation between air monitoring and biological monitoring. Direct detection of toluene, ethylbenzene, and xylene from air sampling and biological monitoring of the urine and blood can be used to determine the extent of solvent exposure to personnel.

Mechanism of Toxicity

Organic solvents have an ototoxic effect on the inner ear structure and can also affect the central and peripheral nervous system [3]. The peripheral nerve is most vulnerable to exogenous organic toxins absorbed through inhalation and transported through the blood [14]. One point of toxicity is the outer hair cells (OHC) of the cochlea located in the inner ear. Solvent ototoxicity of toluene, ethylbenzene, and xylene has been linked to both acute effects caused by direct solvent exposure while chronic ototoxic effects have been associated with reactive intermediates [2]. The formation of reactive oxygen species (ROS) has been linked to cellular damage and thus considered the underlying mechanism of toxicity for noise and chemical induced hearing loss [17]. ROS can cause cell tissue injury by way of the outer sulcus to the OHC and eventually cell death [18]. It is likely that the transit of solvent toxins into the OHC disrupt the recycling of potassium ions (K+) [18]. Organic solvent and ROS generation can interfere with membrane structure and function allowing K^+ to accumulate in the outer tunnel fluid causing toxicity in the outer hair cell and thus initiating cellular damage [2]. The acoustic reflex of the ear prevents continuous acoustic energy or stimulation from penetrating the inner ear. When acoustic reflexes are stimulated, a significant amount of potassium ions (K+) enters the cochlear hair cell increasing the ionic level in the extracellular fluid of the outer tunnel of the organ of Corti [2]. An animal study by Fechter et al. indicated that toluene concentration levels of 400 ppm and 600 ppm combined with noise exposure could result in loss of OHC and auditory function [19]. Noise exposure causes mechanical damage to the stereociliae of the cochlear hair cells as well as micro-lesions of the plasma membrane [20]. Metabolized and unchanged forms of organic solvents can modify the OHC membrane structure making it more fragile and vulnerable to mechanical injury from noise entering the cochlea [21]. The combination of sustained ototoxic and noise exposures can lead to permanent damage to the auditory sensory cells resulting in irreversible hearing loss [2]. Potential exposures to both ototoxic chemicals and noise in the occupational environment should be an important health concern as hair cells cannot be repaired after continuous damage has occurred. Although damage to the hair cells and hearing loss is permanent, hearing loss can be prevented when appropriate cautions are considered.

Military Public Health Significance

Hearing loss can have significant impact to military readiness as well as everyday social situations and quality of life. Service-connected hearing loss is the second most prevalent service-connected disability among veteran benefit recipients and difficult to differentiate from pre-service or recreational hearing loss [22]. According to the Veterans Benefit Administration FY2015 Annual Benefits Report (ABR), over 4.1 million veterans receive an estimated $60 billion in compensation benefits [22]. Over 2.6 million veterans receive compensation benefits for tinnitus and hearing loss which accounts for 94.3% of all service-connected auditory disabilities [22]. This does not include veterans with service-connected hearing loss who did not qualify for disability compensation [23]. Thereby indicating that the total number of veterans with service-connected hearing loss could be greater than stated in available data. In the absence of sufficient evidence of an in-service injury, disease, or symptom of disease the Duty Military Occupational Specialty (MOS) Noise Exposure Listing determines the probability of exposure to hazardous noise exposure [24]. This is a DoD-verified list of occupational specialties for all services. This suggests that the DoD only considers the MOS as a risk factor to hearing loss. Therefore, in the absence of a comprehensive and documented work history, factors that can affect occupational hearing loss remains undefined. Numerous studies recommend chemical exposure assessments in combination with noise hazards regardless of the measured noise level [4]. Military service members are potentially exposed to multiple levels of noise intensities and various chemical concentrations within their career lifetime. A comprehensive exposure assessment of the occupational environment can better characterize the service member's cumulative exposure during their military career and identify job processes and areas that place sailors at increased risk for hearing loss. This will also enable health care professionals to recognize, evaluate and document factors that can potentially increase the risk of hearing loss for service members.

The DoD's comprehensive Hearing Conservation Program (HCP) recommends monitoring ototoxic exposure [25]. A report by the Institute of Medicine (IOM) emphasized the need for improvements to the DoD's HCP to help minimize the adverse effects of noise exposure on military personnel and to improve documentation of hearing loss [23]. The IOM's report recommended further research to better understand the impact of noise exposure on hearing loss and tinnitus that is more specific to military operations and personnel. Among the IOM's recommendations included studies conducted in real-world military settings, sampling of modern military activities, and using reliable data from existing databases to estimate the prevalence, incidence, and severity of NIHL [23]. A comprehensive exposure history of both noise and ototoxic exposures can only improve our current understanding of adverse effects from combined interactions. Noise and air monitoring exposure data is generally maintained in the Defense Occupational Environmental and Health Readiness System-Industrial Hygiene (DOEHRS-IH) database, but are often stored separately from hearing acuity information making it a challenge to relate the combination of chemical and noise exposure levels with health outcomes. In fact, a study conducted by Hughes and Hunting on the U.S. Air Force Reserve personnel failed to show an association between hearing loss and mixed solvent exposure [26]. This study did not evaluate the use and impact of hearing protection or accurately quantify solvent exposure through sample analysis. Exposure levels were collected using available data that did not adequately described extent, concentration, and severity of solvent exposure. This was a significant limitation of the study which led to the conclusion that incomplete and missing exposure documentation for noise and solvent exposure can result in exposure misclassification [26]. Hughes and Hunting strongly emphasized that better quantification of low-level solvent exposures was necessary to improve exposure characterization and link hearing loss association in future studies [26]. However, the difficulty remains in having a detailed and reliable exposure history that includes all hearing loss risks factors, to include non-occupational exposure, for individual exposure agent and how that exposure affects hearing loss [17].

The Department of Defense HCP recommends monitoring but does not clearly define ototoxic chemical exposure and its relevance as part of a comprehensive hearing assessment. A determined effort should be made to further quantify chemical concentrations. The ACGIH TLV® and BEI® Booklet recommends periodic audiograms as well as carefully monitoring of exposure levels for certain chemicals that may result in hearing loss [9]. The U.S. Army Public Health Command Fact Sheet also suggests that workers exposed to potential ototoxic chemicals should be considered for inclusion into the hearing conservation program when exposure levels exceed 50% of the TLV®, despite the noise sound level [5]. While the military hearing conservation program has been established to limit hazardous noise exposure, the data from multiple chemical exposures have not been well characterized or documented. This study aims to better characterize organic solvent exposure based on job processes and work locations.

Purpose of Study

The purpose of this study was to characterize organic solvent ambient concentration levels and identify job processes and work locations on a U.S. Navy aircraft carrier where there is the potential for organic solvent exposure. Ethyl benzene, toluene, and xylene were selected as organic solvents of interest because they are components of aviation fuel, cleaning solvents, degreasers, adhesive resins, paint, and paint thinners and are present in the aircraft carrier work environment. These organic solvents are also described as chemicals with potential ototoxic effects to animals and humans [5, 27].

Literature Review

Animal research is well studied and have historically focused on high solvent concentrations as compared to the OELs and short exposure time ranging from 1 - 4 weeks. Animal studies by Campo et al., Cappaerrt et al., and Maguin et al. have determined that toluene, ethyl benzene, and xylene solvents can cause significant irreversible physiological damage to the cochlea OHC resulting in a hearing threshold shift around the mid-frequency range [28-30]. The mid-frequency range in human hearing lies between 500 to 2000 Hz and correlates to conversations at a normal volume level [31]. Rats were primarily exposed to solvent levels at 4 to 100 times the ACGIH TLV® for approximately 6-8 hours a day depending on the study. The study concluded that these organic solvents had an ototoxic effect on the inner ear that affected structure and function of the OHC. Although these studies provide relevant quantitative data, it does not represent the typical occupational environment where workers are exposed to chronic noise and multiple chemical concentrations. An animal study conducted by Fechter et al. showed that there was a loss of auditory structure and function but only 4 weeks after exposure to toluene and ethylbenzene and noise [19]. The study determined that permanent hearing loss can be observed from exposure to toluene and ethylbenzene even though there were no adverse effects from exposure to noise. Table 1 summarizes the animal studies of organic solvent exposure and OHC loss.

Table 1. Animal Studies

Author	Toxicant	Concentration	Conclusion
Campo, et al. (1997)	Toluene	1500 - 2000 ppm	OHC loss in the mid-frequency range (4-20 kHz region)
Cappaert, et al. (2000)	Ethyl Benzene	300 - 550 ppm	OHC loss in the mid-frequency range (5-16 kHz region)
Maguin, et al. (2006)	Xylene (all isomers)	1800 ppm	OHC loss in the mid-frequency range (4-20 kHz region) for p-xylene (considered ototoxic)
Fechter, et al. (2007)	Toluene	400 ppm	Combined solvent mixture + noise resulted in loss of auditory function and OHC
	Ethyl Benzene	660 ppm	

Previous research involving solvent exposure in humans has been limited. Human epidemiological studies suggest that hearing loss can occur at levels below the regulatory and recommended OEL for noise exposure and organic solvents combined. Although human studies like Morata et al. and Schäper et al. show that prolonged solvent exposure may also be associated with an increased risk of hearing loss, there are very few studies that investigate the ototoxic effect of chemical and noise exposure in a military work environment[6, 32]. The study conducted by Sliwinska-Kowalska et al. aimed to evaluate hearing loss among workers exposed to a mixture of organic solvents at exposure levels considered safe [4]. Most of the solvent concentrations were below the permissible exposure level (PEL) which confirmed previous findings from Morata et al. that showed moderate occupational exposure may increase the risk of hearing loss [6]. In comparison, a study by Hughes and Hunting conducted among U.S. Air Force Reserve personnel did not find an association between low and moderate solvent exposures with hearing loss [26]. Organic solvent exposure was primarily a qualitative assessment and based on historical industrial hygiene records, purchasing reports, and workplace summaries. Relying on qualitative information and the inability to account for external exposures outside of military duties may have led to one of the major challenges with Hughes and Hunting's study. In a study by Kim et al. conducted in the aviation industry, workers that were exposed to both noise and mixed organic solvents were within TLV for noise exposure and within recommended concentration limits [33]. The study concluded that there is a relationship between hearing loss and mixed solvents even at exposure under the recommended limit. In Table 2, several human studies of organic solvent exposure were conducted in the normal work environment to indicate ototoxic effects in conjunction with noise exposure.

Table 2. Human Studies

Author	Toxicant	Concentration	Conclusion
Schräper, et al. (2003)	Toluene	75- 365 ppm	Toluene + noise group had highest relative risk for hearing loss
Sliwinska-Kowalska, et al. (2001)	Xylene Mixture	Mean conc. < OEL	Solvent mixture at moderate concentration increased risk of hearing loss
Morata, et al. (1993)	Toluene	10-70 ppm	Toluene + noise group and toluene-xylene mixture group had a greater risk for hearing loss
	Xylene	12-40 ppm	
Hughes, et al. (2013)	Jet Fuel, Toluene, Xylene	Conc. < OELs	Low and moderate solvent exposure not associated with hearing loss
Kim, et al. (2005)	Toluene-Xylene Mixture	Conc. < TLVs	Noise + solvent mixture had an elevated risk for hearing loss

Research Question

What are the ambient air concentrations of ethyl benzene, toluene, and xylene during shipboard operations in various work locations onboard a U.S. Navy aircraft carrier?

Specific Aims

1. Determine ambient air concentrations of ethyl benzene, toluene, and xylene associated with various job processes in different work locations using 3M^{TM} 3500/3520 Organic Vapor Monitoring (OVM) badges to collect breathing zone air samples.
2. Determine job processes and work locations where sampling results of ethyl benzene, toluene, and xylene concentrations exceed 10 percent of the ACGIH®-TLV TWA, 50 percent of the ACGIH®-TLV TWA, and the ACGIH®-TLV TWA.
3. Narrow possible knowledge gaps involving occupational exposure of ethyl benzene, toluene, and xylene for personnel assigned to Navy aircraft carriers.

Chapter 2: Materials and Methodology

Overview

Pre-existing site-specific Industrial Hygiene (IH) surveys were evaluated to create homogenous sampling groups based on similar job process, work locations, and potential exposure to ethyl benzene, toluene, and/or xylene. The request to conduct this study onboard a Nimitz class aircraft carrier was approved by the appropriate command authority of the Naval Air Force U.S. Atlantic Fleet (COMNAVAIRLANT), Norfolk, Virginia. The Uniformed Services University's Human Research Protections Program Office has determined that this study does not meet the criteria defining human subjects research and does not require an Institutional Review Board (IRB) review.

An initial walk-through of accessible areas on board the USS GEORGE WASHINGTON (CVN 73) aircraft carrier was conducted with the ship's Industrial Hygiene Officer (IHO) to determine work locations and job processes where there was the significant risk for organic solvent exposure at levels of concern. Sample collection occurred over a seven (7) day period, from 30NOV – 4DEC 2016 while the ship was underway. The 3M^{TM} 3500 Organic Vapor Diffusion Monitor (OVDM) was used to collect ambient air samples during 12-hr work shifts. A sample size of 10 per sampling group was sufficient to estimate a mean exposure concentration with a confidence interval width of 1.25 standard deviations [34]. Tables adapted from Leidel, Busch and Lynch suggested a minimum of 10 samples collected for each homogenous sampling group based on at least 95% confidence level of statistical significance and alpha less than or equal to 0.05 [35]. Collected samples were stored at room temperature and secured in the ship's Safety Office. Samples were hand delivered to the U.S Navy Comprehensive Industrial Hygiene

Laboratory (CIHL) and analyzed within three weeks of sample collection. SPSS (version 22) software was used to conduct statistical data analysis on sample results.

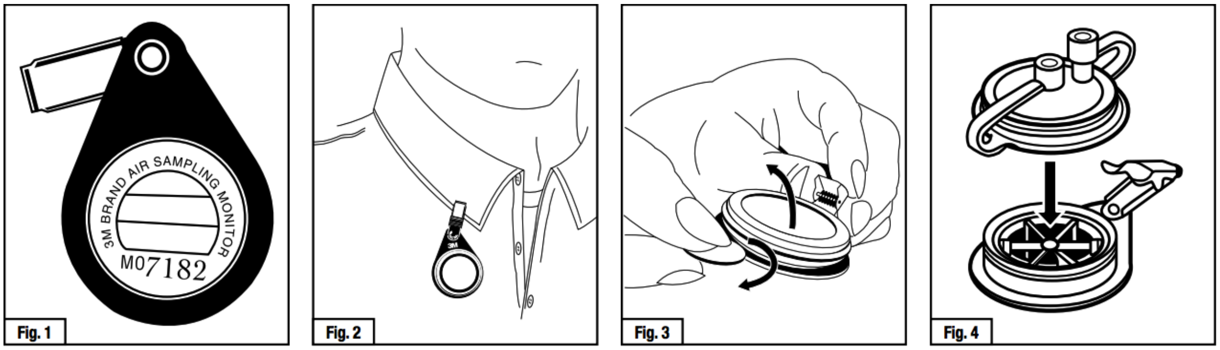
Study Population

Using previously identified selection criteria, homogenous exposure groups of five job processes and five work locations were selected for this study. Job processes selected were jet fuel analysis, oil analysis, fuel pump operation, hazardous material (HAZMAT) issue, and painting. All five jobs were identified as job processes where there was the potential for organic solvent and jet fuel exposure. Work locations selected were Aviation Fuel Quality Control Lab, Oil Analysis Lab, HAZMAT Issue Area, HAZMAT Paint Issue Area, and JP-5 Fuel Pump Maintenance Room. Study population was stratified by job processes and work locations with the exception of painting which occurred in multiple areas throughout the ship.

Sample Collection

Ambient air samples of the working environment were collected using a commercially available diffusion monitor. The 3M™ OVDM is a passive sampling device containing a single charcoal absorbent pad designed to measure contaminant concentration over a measured time interval. The 3M™ monitors were simple to use and the least obtrusive, but caution should be taken when sampling in high humidity. Sample monitors were positioned within the breathing zone range of each participant. Figure 2 illustrates simple instructions for labeling, monitor placement, and proper capping and storage of the sampling monitor. The manufacturer’s guide suggested no more than three compounds should be analyzed for each monitor.

Figure 2. Sampling Instructions for 3M^{TM} OVDM



Personnel performing selected job processes for at least one (1) hour were selected and fitted with a single diffusion monitor. Table 3 shows the parameters used to calculate the minimum sampling time for each solvent. The minimum sampling time was calculated using 10% of the ACGIH TLV® as the lowest acceptable sample concentration for each solvent based on the CIHL laboratory’s limit of quantification (LOQ).

Table 3. Minimum Sample Collection Time

Solvent	10% of TLV (mg/m^3)	Limit of Quantification (µg)	Sampling Rate (mL/min)	Minimum Volume (L)	Minimum Collection Time (mins)
Ethyl Benzene	8.7	10	27.3	1.2	**42**
Toluene	7.5	10	31.4	1.3	**43**
Xylene	43.4	10	27.3	0.23	**8.4**

In Table 4, the maximum sampling time was calculated for each solvent using two times the ACGIH TLV® as the maximum sample concentration. Sample collection time was calculated to ensure sampling time was not exceeded during any point of the sample collection period.

Table 4. Maximum Sample Collection Time

Solvent	2 x TLV (mg/m^3)	OVDM Capacity (mg)	Sampling Rate (mL/min)	mL to m^3	Maximum Collection Time (hours)
Ethyl Benzene	174	24	27.3	10^6	**84**
Toluene	150	>25	31.4	10^6	**88**
Xylene	868	>25	27.3	10^6	**17**

Participants were briefed on the purpose of the study and wear of the diffusion monitor during the full work shift period. Once the sample canister was opened, sample start time and monitor serial number was recorded in the sample log and each participant was fitted with a single sample monitor. Participants wore sampling monitors during normal 12-hr shift period starting at 0700hrs and 1900hrs each day. A unique sample identifier was assigned to each monitor linking it to a specific division, work shift, and job process. The sampling log was maintained during the entire sampling collection period annotating unique sample identifier, monitor serial number, department, ship work areas, job process/job task, and sampling time.

Temperature and relative humidity (RH) were measured in sampling locations to monitor media efficiency as described by manufacturer's guidelines. Temperature ranges were between 65°F and 75°F (18°C to 24°C) during the sampling period. Although, higher temperatures can affect the adsorption process, humidity has a greater impact on the sorbent material as water vapors compete with the contaminant at the adsorption sites decreasing the media capacity. The 3M™ Storage and Recovery Technical Bulletin recommends relative humidity not exceed 80% RH as it may affect sampling, sample storage time, and temperature of sample storage [36]. The RH did not exceed 75% during the sampling period.

At the end of each work shift, monitors were collected from participants, the diffusion film and ring removed, and the elution cap attached. Sampling end time was recorded on the sampling log and all sample information was recorded on the respective sample canisters.

One field and one media blank was included with each group of 10 samples collected. All collected sample monitors were secured and stored at room temperature in the ship's Safety Office. The 3M™ Storage and Recovery Technical Bulletin states that samples can be stored at room temperature for up to three weeks [36]. Samples were promptly hand delivered to the U.S Navy CIHL, Norfolk, Virginia for analysis. Per OSHA Method 7, samples were analyzed by a gas chromatograph (GC) equipped with a flame ionization detector (FID). Carbon disulfide was used to extract contaminants from the charcoal media. Sample media flow rate was 0.0273 L/min for ethylbenzene and xylene and 0.0314 L/min for toluene [37]. Sampling flow rates were verified experimentally in the laboratory by the manufacturer.

Data Analysis

SPSS (version 22) software was used to conduct data analysis. Descriptive statistics were used to determine sample mean and standard deviation for the 12-hr time-weighted average (TWA) sample results. Data analysis showed that sample data did not follow a normal or log normal distribution. Mean exposure for the 12-hr TWA sample results was compared to the ACGIH adjusted 12-hr TLVs. The Brief and Scala model was used to adjust the ACGIH 8-hr TLV to a 12-hr TLV. OSHA and ACGIH both recommend this method when dealing with extended work shifts. Data was then transformed to a binomial outcome to represent data was greater than or less than the LOQ. Results less than the LOQ were assigned the value of zero "0" while results greater than the LOQ were assigned the respective calculated value in ppm.

Statistical analysis using the non-parametric Kruskal-Wallis (K-W) test method was used to determine the statistical significant difference between different job processes and work locations for each organic solvent analyzed.

Chapter 3: Results and Discussion

Results

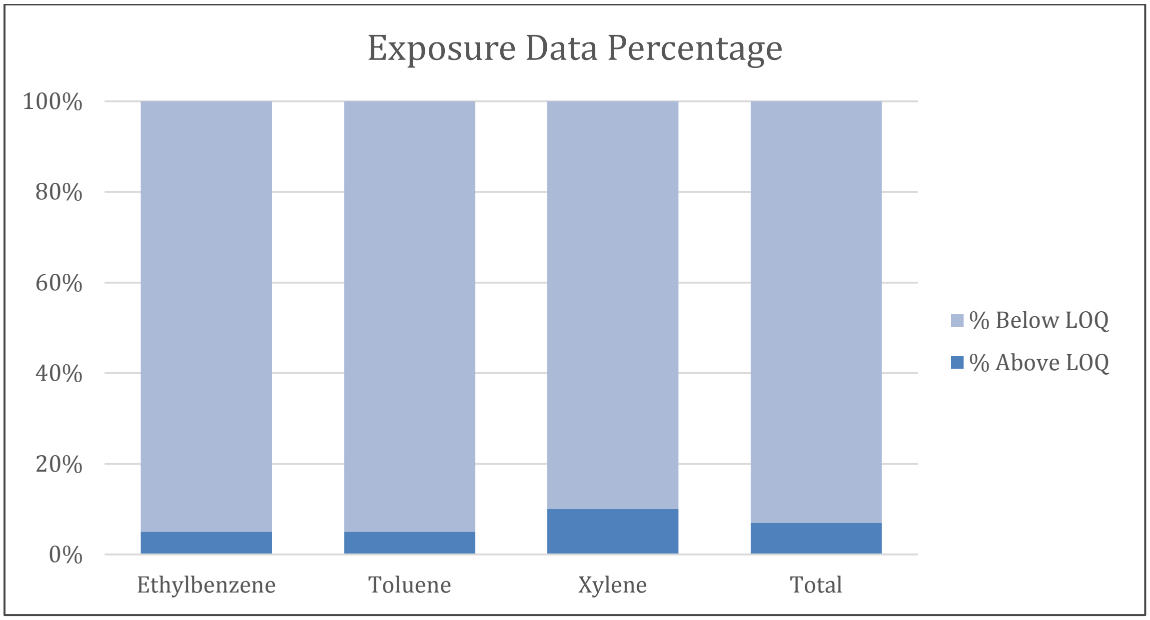
A total of 80 samples were collected and analyzed for ethylbenzene, toluene, and xylene. Job processes identified were conducted in unique areas of the ship, therefore sample results for each job process group are linked to their respective work locations. Painting occurred in multiple work areas throughout the ship and therefore was not assigned a specific work location. Hazmat issue was characterized as a single job process however two different work locations was identified for sampling. Table 5 describes stratification of the homogenous exposure groups and corresponding sample sizes.

Table 5. Stratified Homogenous Exposure Groups

Job Process	Work Location	Number of Samples Collected
Hazmat Issue	Hazmat Issue Area, Paint Issue Area	18
Fuel Testing	V4 QA Lab	27
Painting	Various Deck Locations	14
JP5 Pump Maintenance	JP5 Fuel Pump Room	15
Oil Testing	AIMD Oil Lab	6

Over 90% of sample results were was less than the LOQ, therefore the data set was characterized as a severely censored (75% – 100%) [35]. Painting, Fuel Pump Maintenance, and Oil Testing exposure groups contained 100% censored data. Hazmat Issue and Fuel Testing had results that contained uncensored data (results above the LOQ). Figure 3 illustrates the percentage of samples reported as less than the LOQ categorized by each solvent and total sample results.

Figure 3. Percentage of Data Reported as less than the LOQ



Reported sample concentrations of "<LOQ" were substituted with the LOQ/√2 to determine both the arithmetic mean and standard deviation. All reported sample results for Painting, Fuel Pump Maintenance and Oil Testing exposure groups were less than the LOQ. Hazmat Issue and Fuel Testing exposure groups contained results above the LOQ. For concentrations below the LOQ, sample results can potentially be detected between zero and the LOQ value (10 µg). The LOQ is defined as the lowest concentration that can be reliably quantified by laboratory analytical method. Sample results were reported as the total mass of the analyte collected (µg) divided by the total volume of air sampled (m^3) and then converted to parts per million (ppm).

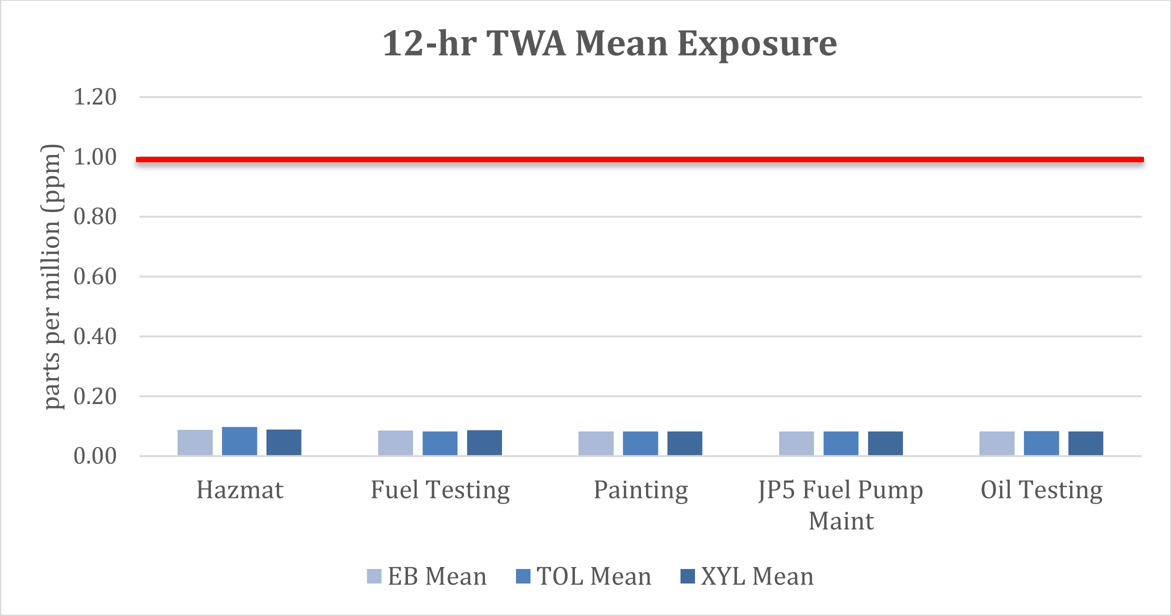
The application of TLVs® are based on an 8-hr work day. ACGIH recommends using the Brief and Scala model when dealing with extended work shifts. The Brief and Scala model used a reduction factor (RF) of 0.5 to proportionately reflect a 50% increase to chemical exposure and a 25% reduction in worker recovery time for a 12-hr work day [38]. For the 12-hr TWAs, ethylbenzene results had a range of < LOQ to 0.184 ppm, toluene results ranged from <LOQ to 0.183 ppm, and xylene results ranged from <LOQ to 0.175 ppm. All sample concentration results were considerably less than the adjusted 12-hr TLV® for ethylbenzene (10 ppm), toluene (10 ppm) and xylene (50 ppm). Table 6 lists the sample mean and standard deviation for each homogenous exposure groups categorized by job process for each solvent.

Table 6. Sample Mean and Standard Deviation for 12-hr TWA (ppm)

	Ethylbenzene		Toluene		Xylene	
HEGS	Mean	SD	Mean	SD	Mean	SD
Hazmat Issue	0.088	0.024	0.097	0.032	0.087	0.010
Fuel Analysis	0.086	0.011	0.082	0.000	0.181	0.025
Painting	0.082	0.000	0.082	0.000	0.082	0.000
Pump Maintenance	0.082	0.000	0.082	0.000	0.082	0.000
Oil Testing	0.082	0.000	0.082	0.000	0.082	0.000

Sample mean exposure for the 12-hr TWAs revealed that the average results were considerably less than 10% of the adjusted 12-hr TLV® for ethylbenzene (1 ppm), toluene (1 ppm) and xylene (5 ppm). Figure 4 illustrates 12-hr TWA mean exposures for ethylbenzene, toluene, and xylene based on homogenous exposure groups categorized by job process. The red line indicates 10% of the adjusted 12-hr TLV® for ethylbenzene and toluene.

Figure 4. Mean Exposure Level for 12-hr TWAs by Job Process

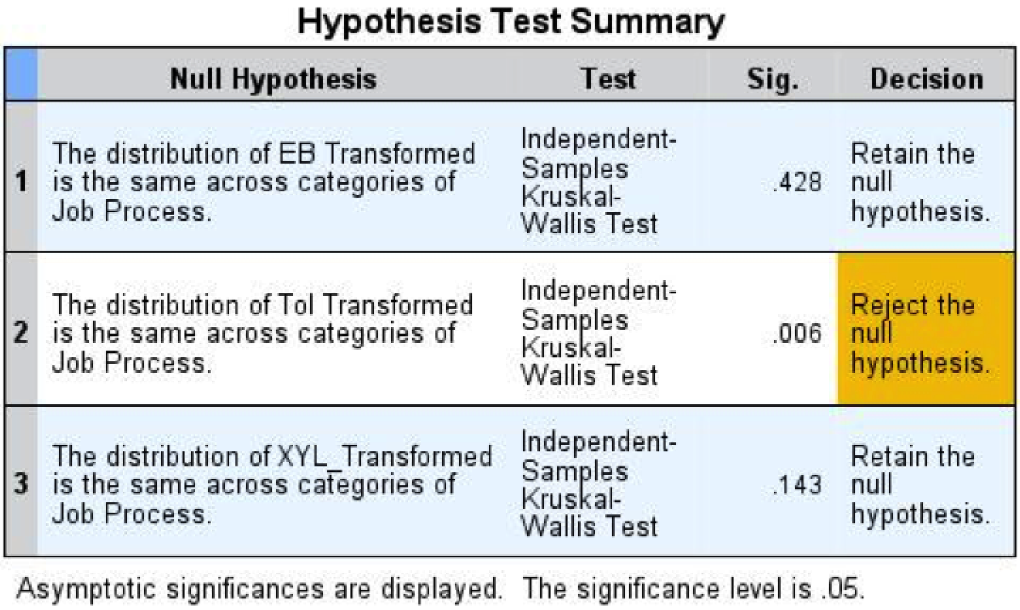


The Kruskal-Wallis (K-W) statistical test was used to determine if there was a statistically significant difference between all five homogenous exposure groups for each organic solvent analyzed. The K-W test is a non-parametric test for when the dependent variable does not meet normality assumptions of Analysis of Variance (ANOVA). Dependent variables were based on the 12-hr TWAs. Data parameters were based on sample results reported less than or greater than the LOQ. Results less than the LOQ were assigned the value of zero "0" while results greater than the LOQ were assigned the respective calculated value in ppm. Each sample result was converted to ranked values in the overall data set and the mean ranks calculated for each exposure group. Because the K-W test uses mean ranks and based solely on the number of observations, this statistical test may not fully describe the original sample data set.

The K-W null hypothesis test assumes that the mean ranks of the exposure groups are all the same for each solvent analyzed. Figure 5 displays the K-W hypothesis test analysis summary. The summary analysis indicated that there were no statistically significant differences ($p > 0.05$)

for ethylbenzene and xylene across all job processes. However, the null hypothesis was rejected for toluene ($p < 0.05$) indicating that there was a statistically significant difference among exposure groups for toluene.

Figure 5. Kruskal-Wallis Analysis of 12-hr TWAs by Job Process



Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of EB Transformed is the same across categories of Job Process.	Independent-Samples Kruskal-Wallis Test	.428	Retain the null hypothesis.
2	The distribution of Tol Transformed is the same across categories of Job Process.	Independent-Samples Kruskal-Wallis Test	.006	Reject the null hypothesis.
3	The distribution of XYL_Transformed is the same across categories of Job Process.	Independent-Samples Kruskal-Wallis Test	.143	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

A post hoc pairwise comparison analysis was conducted to identify which exposure groups were statistically different from each other. Pairwise comparison between Fuel Testing, JP5 Pump Maintenance, Painting, and Oil Testing exposure groups were not considered because sample results for these four groups consisted of 100% censored data for toluene. With the Bonferroni method, comparison tests between HAZMAT Issue and the other exposure groups was conducted using a significance level of $p < 0.012$ (0.05/4). This adjustment method allows for several comparison tests to be made on a single data set by reducing the chances of getting a Type I error while assuring that the overall confidence level is maintained. Comparison between the HAZMAT Issue group and Fuel Testing, JP5 Pump Maintenance, and Painting show that there is a statistically significant difference ($p < 0.012$) between these combinations. However, there was no statistically significant difference between HAZMAT and Oil Testing exposure groups ($p > 0.012$). Table 7 shows the significance value and the Bonferroni adjusted significance value for the pairwise comparison between HAZMAT and four exposure groups for toluene.

Table 7. Pairwise Comparison of Exposure Groups for Toluene

Exposure Group Comparisons	N	Standardized Test Statistic	P-value	Bonferroni P-value
Hazmat Issue Fuel Testing	**18 27**	**3.328**	**0.001**	**0.012**
Hazmat Issue Painting	**18 14**	**2.842**	**0.004**	**0.012**
Hazmat Issue JP5 Pump Maintenance	**18 15**	**2.897**	**0.004**	**0.012**
Hazmat Issue Oil Testing	**18 6**	**2.149**	**0.032**	**0.012**

Discussions

Over 90% of the data reported had concentrations less than the LOQ. This was considerably less than the studies previously discussed. This could suggest that ethylbenzene, toluene, and xylene exposure may not be a factor in assessing the risk of hearing loss on an aircraft carrier. Samples collected from Painting, JP5 Pump Maintenance, and Oil Testing exposure groups reported results all below the LOQ. For further analysis, reported values of "<LOQ" were substituted with values computed from $LOQ/\sqrt{2}$. The American Industrial Hygiene Association (AIHA) recommends other analysis methods for censored data preferable to the substitution method such as the Log-Probit Regression (LPR) method and the Maximum

Likelihood Estimation (MLE) method [35]. The LPR method requires a large data set and prefers a data set with less than 50% censored data and the MLE method, considered the gold standard, can be used for data sets with up to 80% censored data and is best used with a log-normal distribution data set [39]. However, this data set lacked the requirements for using the LPR or MLE analysis method. Therefore, for this study, the substitution method using LOQ/√2 was adequate in estimating solvent concentrations less than the LOQ as the highest reported sample result was less than 10% of the adjusted 12-hr TLV®.

A total of 12 individual sample results were reported over the LOQ. Hazmat Issue and Fuel Testing exposure groups had detected results that ranged from 11μg to 22μg. These results were not unusual for job processes and locations where paint and jet fuel were more commonly and openly used. A low solvent mass could indicate that the chemicals used during selected job processes contained a low percentage of ethylbenzene, toluene, xylene by volume. Additionally, small solvent quantity and a short duration of exposure can also effect sample results based on total collection time. All other sample results were reported less than the LOQ. This could have been due to ethylbenzene, toluene, and xylene was not being present in the chemicals used during the selected job processes or may have been due to solvent concentrations that were too low to be detected during sample analysis. The solvent mean concentration categorized by job process indicated the average exposure was less than 10% of the adjusted 12-hr TLV®. For tasks where ethylbenzene, toluene, and xylene were present in hazardous material used, this could suggest that sufficient ventilation control measures were in place to minimize exposure in each work location selected and throughout the ship.

The 3M™ OVDM was used to collect 80 samples for this study. This passive sampling device contained a charcoal absorbent pad to capture air contaminants over a measure time interval. The organic solvent vapors were absorbed onto a charcoal sorbent at a fixed rate of diffusion whereas active sampling requires the use of a sampling pump to actively move air through a sorbent material. Various publications have evaluated the performance characteristics of diffusive samplers and have determined that results obtained were comparable to active sampling [40].

Although air concentrations of ethyl benzene, toluene, and xylene were considerably less than 10% of the 12-hr adjusted TLV®, the K-W statistical test determined that there was a statistical significant difference for toluene across job processes ($p < 0.05$). Further evaluation using the post hoc pairwise comparison test of the exposure groups for toluene revealed that there was a statistical significant difference between the HAZMAT group and the Fuel Testing, Pump Maintenance, and Painting exposure groups ($p < 0.012$). This outcome was expected as the sample results for all three exposure groups contained 100% censored data. Additionally, toluene results over the LOQ was detected in the HAZMAT group only. However, comparison between HAZMAT and Oil Testing revealed that there were no statistically significant differences between these exposure groups ($p > 0.012$). This is possibly the result of how the mean rank is calculated as it solely depends on the number of observations for each group; only six samples were collected for the oil testing group. No further evaluations were conducted.

There are several limitations of this study that should be noted. Severely censored data was one of the major limitations of this study. Exposure groups like painting, oil testing, and pump maintenance contained 100% censored data. This made it difficult to draw any definitive conclusions about solvent concentrations for each exposure group.

While results obtained in this study showed that there was minimal exposure to ethyl benzene, toluene, and xylene, the potential for exposure to other organic solvents having ototoxic effects was not investigated. Studies by Kim et al., Kaufman et al., and Sliwinska-Kowalska et al. were conducted in the paint and aviation industry where exposure to organic solvent mixtures and jet fuel was identified. Organic solvent mixtures in these studies also included components like Stoddard solvent (white spirit), n-hexane, and methyl ethyl ketone (MEK); potential ototoxic chemicals. Evaluation of additional organic solvents should be considered when conducting a complete exposure assessment.

Another limitation of this study was that sample collection relied primarily on available participants. Convenience sampling was used due to a limited sampling population rather than the preferred method of random sampling [41]. This may have introduced some bias to the study as sample collection could not effectively be randomized between each group. However, because over 90% of the reported results were less than the LOQ, the ability to determine significant variability between each exposure group remains uncertain.

Finally, participants were not directly observed conducting specific job tasks during the entire 12-hr shift work period. Adequate information regarding specific job tasks, task duration, solvent description (e.g. Safety Data Sheet review) and solvent use was limited and not well defined during sample collection for each job process. Also, breaks and time away from job station was not accounted for during sample collection time, therefore exposure to ethyl benzene, toluene, and xylene may be higher than reported.

Chapter 4: Conclusions and Future Studies

Conclusion

The results of this study show that Navy personnel assigned to the aircraft carrier were not exposed to ethylbenzene, toluene, or xylene levels greater than 10% of the ACGIH TLV® for a 12-hr work shift in all five exposure groups. Sample results less than the LOQ suggested that ethylbenzene, toluene, xylene was not present in chemicals used during the five job processes or that solvent concentrations were too low to be detected during sample analysis. Low solvent concentrations during situations where ethylbenzene, toluene, and xylene was present in the chemicals used suggests that adequate ventilation control measures were in place to reduce solvent exposure. Although, all solvent concentrations were well below 10% of the TLV®, personnel assigned to or working in HAZAMT issue may be exposed to higher toluene levels when compared to ethyl benzene and xylene.

Future Studies

Future studies should continue to characterize exposure to chemicals and other materials that may have potential ototoxic effects. Chemicals like Stoddard solvent (white spirit), n-hexane, and methyl ethyl ketone (MEK) have been recognized as potential ototoxic chemicals [5]. These chemicals are components in paint, paint thinners, degreasers, adhesive resin, and cleaning agents. Future efforts should continue to investigate exposures of individual job tasks, task duration, solvent intensity, and task repetition during an entire work shift. Assessment of solvent exposure during specific job tasks compared to the overall solvent exposure may identify and better characterize variation in exposure levels during the total work shift period. The use of direct-reading instrumentation along with active or passive sampling devices should also be considered in future evaluations. Additional studies should also aim to characterize exposure during the entire ship's life cycle to include shipboard operations conducted port side and compare to exposure at-sea. Continuous and periodic evaluation of exposure to ototoxic chemicals in the work environment will benefit future assessment of health outcomes and improve overall efforts to reduce the risk to hearing loss.

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