CDC Workplace Safety and Health

Evaluation of Neurological Dysfunction among Workers Exposed to Trichloroethylene

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The employer shall post a copy of this report for a period of 30 calendar days at or near the workplace(s) of affected employees. The employer shall take steps to insure that the posted determinations are not altered, defaced, or covered by other material during such period. [37 FR 23640, November 7, 1972, as amended at 45 FR 2653, January 14, 1980].

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Abbreviations

ACGIH®	American Conference of Governmental Industrial Hygienists
AL	Action level
°C	Degree Centigrade
BEI®	Biological exposure indices
cc/min	Cubic centimeters per minute
CTE	Chronic toxic encephalopathy
dBA	Decibels, A-scale
FACT™	Functional acuity contrast test
GA	General area
HETAB	Hazard Evaluations and Technical Assistance Branch
HEPA	High-efficiency particulate air filter
HHE	Health hazard evaluation
Hz	Hertz
IARC	International Agency for Research on Cancer
mg/g	Milligrams per gram
mL	Milliliter
NAICS	North American Industry Classification System
NMAM	NIOSH Manual of Analytical Methods
NIOSH	National Institute for Occupational Safety and Health
OEL	Occupational exposure limit
OSHA	Occupational Safety and Health Administration
PBZ	Personal breathing zone
PEL	Permissible exposure limit
ppm	Parts per million
REL	Recommended exposure limit
SD	Standard deviation
SLM	Sound level meter
TCAA	Trichloroacetic acid
TCE	Trichloroethylene
TLV®	Threshold limit value
TWA	Time-weighted average
WHO	World Health Organization

Highlights of the NIOSH Health Hazard Evaluation

The National Institute for Occupational Safety and Health (NIOSH) received a technical assistance request from the Oregon Department of Human Services Environmental and Occupational Epidemiology office. It concerned reports of dementia and neurologic dysfunction among Entek International workers exposed to trichloroethylene (TCE). NIOSH investigators conducted site visits to Entek International and Entek Manufacturing in November 2004 and June 2005.

What NIOSH Did

- We talked with workers about their exposure to TCE.
- We tested workers to see whether TCE exposure affected their vision, balance, manual dexterity, hand/eye coordination, and memory.
- We tested the workers' urine for trichloroacetic acid (TCAA), a TCE breakdown product.
- We took personal breathing-zone air samples for TCE.
- We measured noise exposures in the production area.

What NIOSH Found

- As a group, TCE-exposed workers did worse than unexposed workers in the vision, balance, and manual dexterity tests.
- Urinary TCAA levels among TCE-exposed workers were higher than the levels in the unexposed workers.
- Full-shift personal breathing zone TCE concentrations were below the Occupational Safety and Health Administration permissible exposure limit of 100 parts per million (ppm) but above the NIOSH recommended exposure limit (REL) of 25 ppm.
- Employees wore respirators when performing maintenance activities but not during routine work activities.
- Noise levels exceeded the NIOSH REL in several production departments.

What Entek International Managers Can Do

- Enclose the extrusion and extraction work areas and increase ventilation in the areas where TCE is used.
- Provide respirators for all production employees until ventilation can lower the TCE concentration below the NIOSH REL.
- Provide skin protection for production employees who handle TCE.

What Entek International Employees Can Do

- Wear a respirator during routine work activities in the production area.
- Wear hearing protection while working in any production area.
- Wear gloves (polyvinyl alcohol, Teflon™, Viton™, or other suitable material) when handling unfinished (i.e., "wet") battery separator material.

Extruders, winders, rovers, team leads, and supervisors working in the battery separator production areas were overexposed to TCE. Almost half of those interviewed in these areas reported feeling high or lightheaded at work. Some of these employees also had central nervous system effects that were associated with TCE exposure, and levels of TCAA in their urine that were above recommended values. We recommend that battery separator production employees wear respirators until changes in the production process, ventilation, or work practices reduce airborne TCE concentrations to below the NIOSH REL. Workers should also wear gloves when handling unfinished ("wet") separator material.

On August 24, 2004, NIOSH received a technical assistance request from the Oregon Department of Human Services concerning dementia and neurologic dysfunction among workers exposed to TCE at Entek International in Lebanon, Oregon. In an initial NIOSH site visit in November 2004, NIOSH investigators found GA air concentrations of TCE ranging from 20 to 40 ppm in production areas. A medical questionnaire revealed that 48% of Entek International workers reported feeling high or lightheaded while at work in the last 30 days, compared to 19% of non-TCE-exposed workers at an adjacent facility, Entek Manufacturing.

In a follow-up site visit in June 2005, NIOSH investigators collected full-shift and shorter-term PBZ and GA air samples for TCE on study participants on all four production schedules over a one-week period. Noise exposures were also measured. The medical evaluation included a health questionnaire, five neurobehavioral tests (Grooved Pegboard, Postural Sway, Trail Making, Visual Contrast Sensitivity, and Symbol Color Recode), and biological monitoring for TCAA, a metabolite of TCE. Mean full-shift PBZ air concentrations for TCE were below the OSHA PEL of 100 ppm, but above the extended 12-hour work-shift adjusted NIOSH REL of 21 ppm for extruders, winders, rovers, team leads, and supervisors. Shorter-term (13 to 48 minutes) TCE exposures ranged from 30 to 445 ppm, with the highest concentrations occurring during line maintenance. Production employees wore elastomeric half-mask air-purifying respirators equipped with a combination organic vapor/HEPA filter cartridge during product changeover or line maintenance activities, but not typically during routine work activities. Noise levels exceeded the NIOSH REL in extrusion, winding, palletizing, maintenance, and utility/rover jobs (such as fork lift operators); radios in some work areas contributed to noise exposures. Most workers wore hearing protection (plugs or muffs).

Of 129 study participants, 82 were exposed to TCE. The groups were similar in age, but differed in average tenure and in education levels. The exposed group had a higher prevalence of former and current smokers, and consumed more alcoholic drinks on average than the unexposed. The TCE-exposed group had deficits in the following neurobehavioral tests compared to the non-exposed workers: lower visual contrast sensitivity scores for both eyes at 6 cycles per degree and at 12 cycles per degree for the right eye, a larger postural sway area for the most challenging test condition, and slower completion time in the Grooved Pegboard Test. The median urinary TCAA level in the exposed group was 50 mg/g creatinine (range: 0–223) compared to 0 mg/g creatinine (range: 0–2.2) in the unexposed. A total of 22 TCE-exposed participants (26.8%) had urinary TCAA levels over the ACGIH BEI (100 mg/g creatinine).

Keywords: NAICS 326199 all other Plastic Product Manufactiring, trichloroethylene, TCE, battery separators, TCAA, trichloroacetic acid, neurobehavioral, FACT, visual contrast sensitivity, postural sway, grooved pegboard, noise, respirators, hearing protection, central nervous system

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Introduction

On August 24, 2004, NIOSH received a request for technical assistance from the Oregon Department of Human Services, Public Health Services, Environmental and Occupational Epidemiology office. The request concerned dementia and neurologic dysfunction among workers exposed to TCE at Entek International in Lebanon, Oregon. Following an initial survey at Entek International on November 1–3, 2004, we provided an interim letter dated April 8, 2005, to the State of Oregon and the company containing our preliminary results and a recommendation to perform additional testing at the Entek International facility. A follow-up survey was conducted in June 2005. Results from the industrial hygiene sampling were provided to the State of Oregon and Entek International in an interim letter dated November 28, 2005. Summary results from the urinary TCAA and neurobehavioral testing were provided to the State of Oregon and Entek International in a letter dated May 5, 2006. We also provided individual medical results separately to all study participants.

Process Description

In 1987, Entek International began commercial production of its main product, microporous polyethylene battery separator material for lead-acid battery applications. Low electrical resistance, strength, flexibility, high puncture resistance, and consistent quality (the absence of pinholes) are all critical in producing effective battery separators. Battery separator material is produced by mixing ultra-high density polyethylene polymer and amorphous silica in mineral oil. This mixture is extruded into a flat sheet, and the excess oil is removed from the product by using TCE in a patented extraction process. This extraction process precisely removes excess oil from the separator sheet, leaving only the oil percentage required for optimum separator performance. The battery separator material is placed in an oven to remove any excess TCE, and the final product is wound onto rolls for shipment (Photo 1). Job titles in the production areas include extruder, winder, rover, utility, pelletizer, cut-to-fit, and maintenance. During both NIOSH surveys production employees (except rovers, utility, and maintenance) were typically assigned to one production line for an entire shift.

Photo 1: Roll of Battery Separator Material

Much of the manufacturing process is enclosed within ventilated metal cabinets, and most of the TCE used to remove the oil from the battery separator material is recycled. However, based on historical data collected by Entek International, airborne TCE concentrations have ranged from approximately 20 to 40 ppm near the work stations of the employees involved in battery separator manufacturing.

At the time of this evaluation, Entek International employed 142 workers as production and maintenance workers, shippers, laboratory technicians, floor supervisors, and office personnel. Battery separator production operated 24 hours a day, 7 days a week, with four work schedules. Employees on schedules 1 and 2 worked 12-hour shifts Sunday through Tuesday and a 6-hour shift on Wednesday. Workers on schedules 3 and 4 worked a 6-hour shift on Wednesday and 12-hour shifts Thursday through Saturday.

ASSESSMENT

Initial Survey

An initial survey at Entek International was conducted on November 1–3, 2004. Following an opening conference and walk-through tour of the facility, investigators collected TCE samples in manufacturing areas by using direct reading colorimetric detector tubes, used sound level meters to measure noise levels, and administered a medical questionnaire. The medical questionnaire collected information on basic demographics, job and medical history, and acute and chronic neurobehavioral symptoms. Questionnaires were administered to all eligible employees in the production area of Entek International who were potentially exposed to TCE. For a comparison group of TCE-unexposed workers, the questionnaire was also given to employees at Entek Manufacturing, an adjacent company that designed and built all the manufacturing, processing, and tooling equipment used at Entek International. Only Entek International production employees worked on a production shift rotation. Entek Manufacturing employees worked a Monday through Friday 8-hours/day work schedule. The initial survey findings prompted NIOSH investigators to conduct a follow-up survey to more completely characterize TCE exposures and determine if neurobehavioral abnormalities were associated with TCE exposure.

Follow-up Survey

A follow-up survey was conducted on June 19–26, 2005. Full-shift PBZ air samples were collected for TCE on 82 exposed participants on all four production shifts over a one-week period.

Job titles sampled included extruder, winder, maintenance, rover, utility, pelletizer, and cut-to-fit (a job producing small quantities of custom-sized battery separators). In addition, shorter-term task-based air samples for TCE (sampling times ranging from 13 to 48 minutes) were collected during activities such as line maintenance and product line change-over. Higher TCE concentrations were anticipated during these activities based on a review of historical data collected by the company. GA air samples were collected to evaluate any potential TCE exposure for the unexposed group. All air samples for TCE were collected on activated charcoal tubes according to NMAM Method 1022. Noise exposures, using both SLMs and noise dosimeters, were collected on Entek International workers in job categories similar to those listed for the TCE air sampling. Appendix B describes the air and noise sampling methods used in this evaluation.

The exposure groups were determined by employee job titles and area of the facility where the employees worked. Workers in the exposed group included production employees who had daily direct exposure to TCE for their full shift. Workers in the unexposed group included office and production employees from Entek Manufacturing and office workers from Entek International, none of whom had TCE exposure. Workers with daily indirect exposure or intermittent exposure were excluded from the evaluation. All participants completed a questionnaire that collected information on work history, medical history, and personal characteristics. Participants' urine was analyzed for a metabolite of TCE (urinary TCAA). Finally, each participant completed the following neurobehavioral tests:

1. Grooved Pegboard Test–manual dexterity
2. Postural Sway–postural stability
3. Trail Making–eye-hand coordination
4. Symbol Color Recode–psychomotor function and implicit learning
5. FACT™–visual contrast sensitivity and visual search

The medical questionnaire, the five neurobehavioral tests, and biological monitoring for TCAA are discussed in greater detail in Appendix B.

Statistical Analysis

SAS Version 9.1.3 software (SAS Institute, Cary, North Carolina) was used for the statistical analyses. Results with p-values less than or equal to 0.05 were considered statistically significant. Because distributions of some of the continuous outcome variables were skewed, a log transformation was applied when it helped to satisfy statistical model assumptions. Regression models were constructed to examine possible relationships between exposure to TCE and the measures for each neurobehavioral test while controlling for potential confounders (variables that could affect the exposure/outcome relationship). Chi-square or Fisher's exact tests were used to compare the prevalence of symptoms between exposure groups.

RESULTS AND DISCUSSION

Initial Survey

TCE concentrations from short-term area air samples ranged from 20 to 40 ppm along the extruding, extracting, and winding areas of several production lines and were similar to the historical air sampling data collected by the company. Although all Entek International employees were part of a respiratory protection program, they were not required to wear organic vapor respirators in the production areas.

Questionnaires were administered to 42 eligible employees in the production area of Entek International, which is 100% of employees present on the days of the survey. The demographics for these workers are shown in Table 1.

Table 1. Personal Characteristics by Exposure Group (Initial Survey)

	Entek Inter. (n=42)	Entek Mfg. (n=16)
Participation Rate	98%	89%
Age (mean years)	40.3	31.3
Years at Entek (mean)	11.6	3.7
Male	100%	100%
Alcohol Consumption in past 30 days		
# of days w/at least one drink (mean)	5.6	10.0
# of drinks on an occasion (mean)	2.4	2.6
# times had 5 or more drinks on an occasion (mean)	1.3	3.1
Smoking Status		
Never	38%	33%
Former	46%	30%
Current	17%	38%

Results and Discussion (continued)

Sixteen Entek Manufacturing employees with no TCE exposure were chosen as a comparison group. As shown in Table 2, the medical questionnaire revealed that 48% of Entek International workers, when asked about a variety of symptoms experienced during the workday over the last 30 days at work, reported feeling high or lightheaded, compared to 19% of Entek Manufacturing workers ($p<0.05$).

Table 2. Prevalence of Acute Symptoms Experienced during the Workday (Initial Survey)

	Entek Inter. (n=42)	Entek Mfg. (n=16)
Headache	41%	38%
Lightheaded or high	48%*	19%*
Tired	57%	56%
Difficulty concentrating	17%	19%
Trouble remembering things	19%	31%
Confusion	14%	19%
Irritable	41%	44%
Incoordination	12%	13%
Loss of muscle strength	10%	13%

*indicates a significant difference ($p<=0.05$).

In addition, when asked about symptoms experienced in the last 30 days, but not limited to the workplace, Entek International workers reported feeling high from chemicals at work, lightheadedness or dizziness, heart palpitations, difficulty falling asleep, difficulty driving home because of dizziness or tiredness, and a lower tolerance for alcohol significantly more frequently than Entek Manufacturing workers (see Table 3).

Table 3. Prevalence of Symptoms Experienced in the Past 30 Days (Initial Survey)

Symptoms	Entek Inter. (n=42)	Entek Mfg. (n=16)
Tire more easily	38%	25%
Lightheaded or dizzy	45%	19%
Difficulty concentrating	29%	6%
Confused or disoriented	14%	0%
Trouble remembering things	31%	31%
Relatives noticed problem with memory	17%	13%
Make notes to remember things	38%	44%
Difficulty understanding meaning of printed materials	14%	13%
Felt irritable	60%	50%
Felt depressed	41%	19%
Heart palpitations	31%	6%
Seizure	0%	0%
Sleeping more often	26%	13%
Difficulty falling asleep	36%*	6%*
Incoordination or loss of balance	19%	0%
Loss of muscle strength in legs or feet	14%	0%
Loss of muscle strength in arms or hands	7%	6%
Difficulty moving fingers or grasping things	19%	6%
Numbness or tingling in fingers	12%	6%
Numbness or tingling in toes	2%	0%
Headaches at least once a week	38%	25%
Difficulty driving home from work because felt dizzy or tired	31%*	0%*
Felt high from chemicals at work	52%*	0%*
Lower tolerance for alcohol	26%*	0%*

* indicates a significant difference (p<=0.05).

Follow-up Survey

TCE Exposure

Over 7 consecutive days a total of 274 PBZ air samples were collected. Figure 1 displays the mean PBZ TCE exposures by work schedule, while Table 4 summarizes the mean TCE concentrations by job title.

As shown in Figure 1, the higher average exposures measured on work schedules 1 and 2 during the first day of this evaluation (Sunday) are likely due to line maintenance activities that occurred during these shifts that required replacing roller bearings and rethreading new material onto take-up spools. While these line maintenance activities could result in much higher shorter-term TCE exposures for some extruders and winders (see Table 5), mean

TCE exposures among all battery separator production employees were similar, ranging from 28 to 37 ppm, TWA over a 12-hour work schedule.

Figure 1: Mean PBZ TCE Concentrations, by Work Schedule

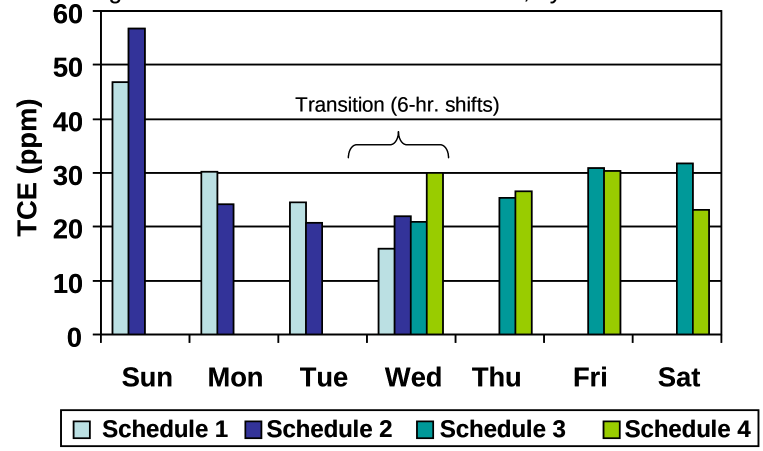


Table 4. Full Shift TWA TCE Exposures, by Job Category

Job	Number	TCE Concentration (ppm) Mean	Median	Range
Extruder	74	37	34	1.7 – 130
Winder	89	33	28	12 – 89
Maintenance	31	15	15	3.7 – 52
Rover	15	33	26	12 – 58
Team Lead	21	35	30.	18 – 82
Supervisor	11	28	20.	11 – 98
Pelletizer	12	11	9.0	4.0 – 30.
Utility	17	12	8.7	3.9 – 29
Cut-to-size	4	3.1	2.7	2.0 – 4.8
NIOSH REL		25 *		
OSHA PEL		100		

One sample was collected during rewinding, an infrequently performed activity. The rewinding operator was exposed to a TCE concentration of 13 ppm, TWA.
* The NIOSH REL is for occupational exposures up to 10 hours. Adjusted for a 12-hour work shift, the REL is reduced to 21 ppm.

Table A1 (see Appendix A) lists the results from the 517 individual air samples collected during the follow-up evaluation, arranged by job, shift, and day. In most instances TCE-exposed study participants had two PBZ air samples collected over their 12-hour work shift. This was done to avoid overloading the charcoal tubes used to collect TCE. For each participant, results from both tubes were combined to calculate an overall TWA for the entire work shift.

A total of 16 shorter-term PBZ air samples (sample times ranged from 13 to 48 minutes) were collected during non-routine work tasks (Table 5); the sampling time varied depending on the work activity performed. The highest TCE air concentration (450 ppm) was measured on an extruder operator removing transition roller bearings on Line 8. This activity required the extruder operator to open the side panels on Line 8 and reach inside to access the bearings.

Entek International had a respiratory protection program, and elastomeric half-mask air-purifying respirators equipped with a combination organic vapor/N100 filter cartridge were available (but not required) during routine work activities. The company did require that Entek International production workers use these respirators during a product changeover or when performing line maintenance activities. The extruder operator working on Line 8 was observed correctly wearing this type of respirator during this maintenance activity. However, this type of respirator, when correctly worn, only provides protection to TCE concentrations up to 250 ppm, based on a protection factor of 10. The minimum level of respiratory protection from a TCE exposure of 450 ppm is an elastomeric full-face air purifying respirator equipped with an organic vapor cartridge.

Production employees occasionally handled unfinished (i.e., “wet”) battery separator material that contained a higher percentage of TCE than the final product during product changes or line maintenance activities. Some workers wore gloves (cloth or nitrile) during these activities.

No airborne TCE was measured in the non-exposed work areas (Entek International office area and Entek Manufacturing office and manufacturing areas), based on the results from 16 GA air samples collected during the follow-up survey. The minimum detectable TCE concentration for sampling conducted in these non-exposed work areas was 0.10 ppm.

At the time of this evaluation, Entek International had an engineering plan underway to reduce TCE exposures. The multi-year plan consisted of installing additional local exhaust and general ventilation in the battery separator production area and building walls to separate the extrusion, extraction, and winding sections of the production lines.

Table 5. Shorter-term TCE exposures, by Job Task

Job	Line No.	Activity	Time (min.)	TCE (ppm)
Winder	3	Line start-up following maintenance	48	89
Extruder	3	Line start-up following maintenance	44	59
Winder	8	Line start-up, collecting excess material at winding end	45	95
Extruder	8	Line start-up, collecting excess material at extrusion end	40	120
Winder	7	Assisting Line 8 operators in start-up	37	160
Extruder	8	Line start-up, extraction doors open, raised tank covers	16	68
Winder	8	Line start-up, threading new material onto spools	17	64
		Line start-up, threading new material onto spools	19	80.
		Line start-up, threading new material onto spools	20	48
Team Lead	1	Change-over to new product, line not yet running	16	30.
		Line start-up	26	37
Winder	1	Line start-up, threading new material onto spools	22	59
Extruder	8	Line maintenance, transition roller at extractor and dryer	33	220
		Line maintenance, removing transition roller	13	450
		Line maintenance, replacing transition roller bearings	27	67
		Line maintenance, reinstalling transition roller	14	47

Note: Respiratory protection (NIOSH-approved half face-piece respirators with combination organic vapor cartridges and N100 filters) were worn by employees performing these short-term activities.

Noise

Instantaneous noise monitoring results are shown in Table 6. Noise levels around the extruders were higher than in the adjacent winding areas. The regrind operation, which was only performed intermittently when scrap material needed to be recycled, was the loudest activity, followed by the pelletizer operation. The highest noise levels in line 3 and 4 winder areas were attributed to radios on employee work desks.

Table 6. Noise Levels

Area/Activity	dBA	Comments
Regrind	95–97	This job is performed infrequently
Extruder, Line 8	85–87	
Extruder, Line 7	82–85	
Extruder, Line 2	88–91	At work desk 87–88 dBA
Extruder, Line 1	88–94	At work desk 87–88 dBA
Winder, Lines 7 & 8	78–80	Radio on work desk 89 dBA
Winder, Lines 3 & 4	80–82	Radio on work desk 85 dBA
Winder, Lines 1 & 2	75–76	No radio in winder area

Table 7 contains the results from 35 full-shift personal noise dosimetry samples collected on the following job tasks: extrusion, winding, palletizing, regrind, maintenance, team lead, supervisor, rover, and forklift. These dosimeters integrated noise exposure data using both NIOSH and OSHA criteria (see Appendix C). Fourteen of the 35 samples exceeded the OSHA action level, four samples exceeded the OSHA PEL, and 28 samples exceeded the NIOSH REL. A complete listing of the personal noise dosimeter results is shown in Table A2 (see Appendix A).

Table 7. Noise Dosimeter Ranges, by Job

Job	No. of Samples	Noise Dose %				Comment
		OSHA PEL	% > PEL	NIOSH REL	% > REL	
Extruder	9	3.4 – 107	1 (11%)	40 –736	8 (89%)	These noise dose percentages are accumulated during a work day, with 100% representing the maximum allowable daily dose.
Winder	10	5.7 – 31	0	68 – 276	7 (70%)	
Maintenance	3	11 – 19	0	102 –141	3 (100%)	
Team Lead	3	14 – 24	0	118 –216	3 (100%)	
Pelletizer	3	106 – 154	3 (100%)	560 – 755	3 (100%)	
OSHA PEL		100				
NIOSH REL				100		

Questionnaire

The two exposure groups were determined by an employee roster coded by the company. Workers chosen for the TCE-exposed group were reported to have a daily direct exposure for three 12-hour shifts and one 6-hour shift. Workers in the TCE-unexposed group were reported to have no exposure to TCE. Workers with daily indirect exposure or intermittent exposures were excluded from the study. As shown in Table 8, of the 129 participants in the study, 82 were exposed to TCE. The participation rate was 67.9%.

The groups were similar in age, but differed by the number of years at Entek. The groups were different in education levels, with the unexposed group attaining a higher educational level than the exposed group. The exposed group also had higher prevalences of former and current smoking. The exposed group consumed a median of 12 alcoholic drinks in the last 30 days compared to 4 drinks for the unexposed.

Table 8: Personal Characteristics, by Exposure Group

	Unexposed (n=47*)	Exposed (n=82*)
Age (mean years)	40.3	41.1
Years at Entek (median)	6	12.5
Work hours per week (median)	42	42
# of alcoholic drinks consumed in last 30 days (median)	4	12
Male	68%	100%
Education		
Less than high school	0%	2%
High school diploma	9%	50%
Some college	49%	40%
College degree or higher	43%	7%
Smoking status (cigarettes, cigars, pipes)		
Never	72%	46%
Former	17%	28%
Current	11%	26%
Diabetes	2%	7%
Hypertension	11%	10%
Glaucoma	0%	0%
Cataracts	0%	1%
Other eye problems	9%	4%
Eye surgery	2%	2%
Corrective lenses for reading	50%	43%
Colorblind	6%	15%
Head Injury	11%	22%

*Sample size ranged from 46-47 for the unexposed and 81-82 for the exposed due to missing data.

Urinary TCAA

The median creatinine-adjusted urinary TCAA level in the TCE-exposed group was 50 mg/g (range: 0–223) compared to 0 mg/g creatinine (range: 0–2.2) in the unexposed ($p<0.01$). Levels of TCAA in the general population are <5 mg/g creatinine. A total of 22 TCE-exposed participants (27%) had urinary TCAA levels over the ACGIH BEI (100 mg/g creatinine adjusted). Creatinine is used to adjust for the varying density in urine samples. Urinary TCAA levels in the exposed group were significantly correlated with PBZ TCE levels ($r=0.48$, $p<0.01$).

Grooved Pegboard

The adjusted mean grooved pegboard completion times were significantly longer for the exposed group (98.3 seconds) than he unexposed group (82.1 seconds, $p<0.01$). We adjusted for age, gender, education level, head injury, diabetes, and alcohol consumption in last 30 days.

The finding that TCE-exposed workers performed this test significantly slower than unexposed workers is consistent with a study of toluene-exposed women [Foo et al. 1990] and persons chronically exposed to TCE-contaminated well water [Kilburn and Warshaw 1993].

Postural Sway

The postural sway variables were log-transformed due to the skewed distribution of the data. After controlling for the effects of height, weight, foot length, age, alcohol consumption in last 30 days, history of head injury, and diabetes, we found a significant relationship between exposure to TCE and the sway area on the most demanding condition only (soft foam surface-eyes closed condition), with the exposed having a greater sway area than the unexposed (p=0.05). There was no difference in the measured sway length between the exposed and unexposed groups in the soft foam surface-eyes closed condition.There were no significant differences between exposed and unexposed groups for the postural sway area and length for the other three test conditions (hard surface-eyes open; hard surface-eyes closed; and soft surface-eyes open).
The finding that TCE-exposed workers in this evaluation had a significantly larger sway area for the most challenging condition (soft surface-eyes closed) differs from a study of sewer workers exposed to solvents that found significant differences for the hard surface-eyes closed and soft surface-eyes open conditions [Kuo et al. 1996]. In that study, postural sway was significantly correlated with urinary TCAA levels in the easiest testing condition (hard surface-eyes open).

Table 9. Postural Sway Results

Test Condition	Exposure Group	Mean Postural Sway			
		Area	*p*-value	Length	*p* value
Hard surface-eyes open	Exposed Unexposed	2.5 cm^2 2.8 cm^2	0.33†	34.1 cm^2 34.6 cm^2	0.80†
Hard surface-eyes closed	Exposed Unexposed	3.4 cm^2 3.6 cm^2	0.58†	49.2 cm^2 50.5 cm^2	0.72†
Soft surface-eyes open	Exposed Unexposed	4.3 cm^2 3.9 cm^2	0.27†	48.8 cm^2 45.0 cm^2	0.08†
Soft surface-eyes closed	Exposed Unexposed	9.6 cm^2 7.7 cm^2	0.05‡*	71.6 cm^2 78.3 cm^2	0.17†

† Adjusting for height, weight, foot length, age, alcohol consumption, head injury, and diabetes.
‡ Adjusting for height and age.
* Indicates a significant difference ($p \leq 0.05$).

Trail Making A and B

The time measurements for forms A and B were log transformed to provide a more normal distribution of the data for analysis.

No significant differences were found between the exposed and unexposed groups. The geometric mean Trail Making A time was 22.7 seconds for the exposed group and 21.1 seconds for the unexposed group (p=0.31) after adjusting for age, history of head injury, educational attainment, and alcohol consumption. A similar result was obtained for the Trail Making B time, with an adjusted geometric mean of 50.7 seconds for the exposed compared to 48.5 seconds for the unexposed (p=0.62).

A study of 42 men with long-term (average 25 years) exposure to organic solvents found that declining performance on Trail Making Test B related to exposure duration [Ellingsen et al. 1997]. Significant differences were found between toluene-exposed female workers and controls for the Tests [Foo et al. 1990]. Although we did not find a significant difference between groups for either the Trail Making A or B tests, the mean time on both tests for the exposed was longer than for the unexposed group. It is possible that the changes in the exposed group were so subtle that neither Trail Making Test was able to detect them.

Visual Contrast Sensitivity

Five participants were excluded from this analysis because of previous eyes surgeries, macular degeneration, or eye injury. After controlling for diabetes, head injury, age, current cigarette smoking, and alcohol consumption in last 30 days, there was a significant difference between the exposed and unexposed groups at a spatial frequency of 6 cycles per degree for both eyes, with the exposed having lower scores than the unexposed (see Table 10). After controlling for the effects of diabetes, history of head injury, age, current cigarette smoking, and alcohol consumption in the last 30 days, we found no statistically significant relationship between TCE exposures and contrast sensitivity scores at spatial frequencies 1.5, 3, 12, and 18 cycles per degree. Cycles per degree refers to to the number of alternating light and dark bands within one degree of visual angle. Contrast refers to the difference in intensity (expressed as a percent) between the light and dark bands, with white to black having a 100% contrast.

Table 10. Adjusted Mean Visual Contrast Sensitivity Scores by Exposure Group*

Spatial frequencies [cycles per degree]	Group	Left Eye		Right Eye	
		Mean	*p*-value	Mean	*p*-value
1.5	Exposed	78.6	0.10†	82.2	0.59†
	Unexposed	86.2		84.6	
3	Exposed	129.3	0.14†	127.4	0.73
	Unexposed	139.6		130.0	
6	Exposed	122.1	**0.05†**	115.0	**0.03†**
	Unexposed	139.4		136.8	
12	Exposed	55.9	0.12†	53.5	**0.04‡**
	Unexposed	66.2		68.0	
18	Exposed	25.4	0.34†	22.5	0.19†
	Unexposed	29.3		27.8	

Comment: Values that differ significantly are shown in bold font.
* Sample sizes for analyses ranged from 114–115.
† Controlled for diabetes, head injury, age, current cigarette smoking, and alcohol consumption in last 30 days.
‡ Controlled for current cigarette smoking.

As shown in Figures 1 and 2, statistically significant relationships were found between TCE exposures and contrast sensitivity scores at spatial frequencies 6 (left and right eyes) and 12 (right eye only). Because the contrast sensitivity score for the right eye of 12 cycles per degree approached statistical signficance, we did additional modeling to remove potential confounders that had no meaningful effect on the relationship between TCE exposure and contrast sensitivity scores. After removing the unnecessary potential confounders this relationship became significant (p=0.04).

Figure 1. Contrast Sensitivity Scores (CSS), Right Eye*

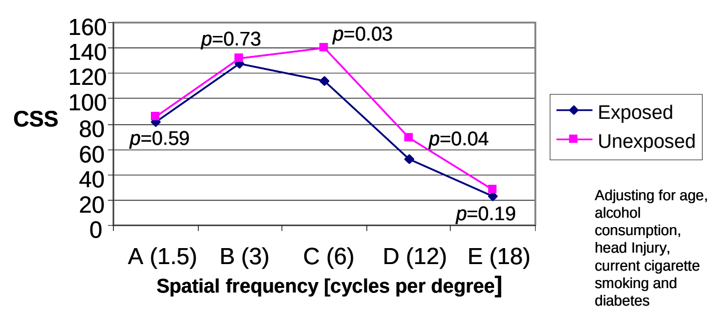
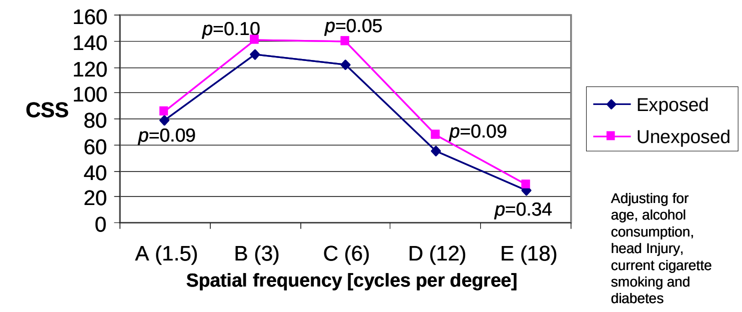


Figure 2. Contrast Sensitivity Scores (CSS) - Left Eye*



Similar results have been reported in workers exposed to a mixture of organic solvents [Gong et al. 2003]. In a study evaluating cumulative styrene exposure and visual functions, significant contrast sensitivity deficits in the intermediate spatial frequencies were found among those in the upper cumulative exposure group (as with this evaluation), but no relation between bio-indicators of current exposure and contrast sensitivity loss were found [Castillo et al. 2001]. This suggests that contrast sensitivity loss reflects long-term cumulative exposure and chronic damage to the neuro-optic pathways. Other researchers found that people exposed to the highest levels of TCE through a municipal water supply (>15 parts per billion) performed significantly worse on the contrast sensitivity tests and had higher mean scores for confusion, depression, and tension than unexposed controls [Reif et al. 2003]. This study concluded that there was evidence that long-term exposure to low concentrations of TCE is associated with neurobehavioral deficits. It has also been hypothesized that the intermediate spatial frequency channel neurons in the visual system may be more vulnerable to organic solvent toxicity than those of low or high spatial frequency [Boeckelmann and Pfister 2003].

Symbol Color Recode Test

After adjusting for age, diabetes, head injury, current cigarette smoking, and alcohol consumption in last 30 days, there was no significant difference between the exposure groups in their reaction times (p=0.56) or number of correct responses (p=0.73) for test 1. The results were similar for the reaction times (p=0.99) and number of correct responses (p=0.16) for test 2.

Results and Discussion (continued)

Because the symbol color recode test used in this study is a new test designed by NIOSH researchers, comparison findings are not available. The hypothesis behind the development of this test is that the subtle effects of low-level chemical exposures on the nervous system may be revealed in tests of higher cognitive functions such as implicit learning. The symbol color recode test is similar to the Digit Symbol Test and Symbol Digit Modalities Test, but reduces the motor component of these tests by pairing symbols with colored keys on a separate keypad (rather than pairing symbols with numbers, that require participants to hand-write during the recode task). While other researchers did find significantly poorer performance on the digit symbol test in people who were exposed to TCE in a municipal water supply [Reif et al. 2003], the lack of significant results in this HHE may suggest that there is no relationship with TCE exposure. However, it was also observed that the subtle manipulation of this unvalidated test, designed to test implicit learning of the symbol-color pairings, had been unintentionally communicated to participants in both groups. This effectively negated the potential sensitivity of this measure.

Conclusions

NIOSH investigators determined that most battery separator production employees were exposed to airborne concentrations of TCE above the extended work shift-adjusted NIOSH REL of 21 ppm in five job categories evaluated: extruder, winder, rover, team lead, and supervisor. While levels for some individual production employees exceeded the OSHA PEL of 100 ppm, none of the mean full-shift PBZ air concentrations (by job category) exceeded this limit. Results from shorter-term PBZ exposures for TCE ranged from 30 to 445 ppm, with the highest concentrations occurring during roller maintenance activities on Line 8.

A medical questionnaire revealed that 48% of Entek International workers reported feeling high or lightheaded while at work in the last 30 days, compared to 19% of non-TCE-exposed workers at an adjacent facility, Entek Manufacturing. We found statistically significant evidence of neurobehavioral deficits in three of the five tests administered to Entek International workers which we associated with their TCE exposure. These deficits were lower visual contrast sensitivity scores in the intermediate spatial frequencies, significantly larger postural sway area under the ost challenging condition (standing on a soft surface with eyes closed), and slower completion of the Grooved Pegboard Test. These findings may not present with any symptoms or signs which are evident upon clinical examination. Lower performance on these tests has been associated with alcohol consumption, taking certain medications, other conditions like diabetes, and age, all of which we attempted to control for with our statistical analyses. Additionally, 22 employees had urinary TCAA levels above the ACGIH BEI of 100 mg/g creatinine.

Some battery separator production employees wore cotton or nitrile gloves when handling unfinished (i.e., "wet") battery separator material and during product changes or line maintenance. While urinary TCAA levels in the exposed group were significantly correlated with PBZ TCE levels ($r=0.48$, $p< 0.01$), skin absorption is also possible since neither cotton or nitrile gloves offer protection from TCE.

Entek International had a respirator program. However, at the time of this evaluation the extruders, winders, rovers, team leads, and supervisors in the battery separator protection areas were not required to wear respirators while performing their routine work tasks. The elastomeric half-mask, air-purifying respirators equipped with a combination organic vapor/N100 filter cartridge that were worn by battery separator production workers during product line changes and line maintenance activities were not sufficiently protective considering the higher shorter-term TCE exposures measured in this evaluation.

Noise levels exceeded the NIOSH REL in extrusion, winding, palletizing, maintenance, and utility/rover jobs (such as fork lift operators). Radios present in four of the six winder lines contributed to employee noise exposures. While noise exposures exceeded the NIOSH REL, most employees wore hearing protection while in the production areas.

The Entek International ventilation engineering plan reviewed during this evaluation included additional local exhaust and general dilution ventilation, and separating the extrusion, extraction, and winding areas with solid walls from floor to ceiling. The goals of this plan were to lower TCE concentrations throughout the battery separator production areas and to reduce the number of employees working in the areas with the highest mean TCE exposures.

RECOMMENDATIONS

1. Use engineering controls, such as local exhaust ventilation, general dilution ventilation, and enclosures to lessen or eliminate the need for routine respiratory protection from TCE exposures in the battery separator production areas.

2. Employees working as extruders, winders, rovers, team leads, and supervisors should wear elastomeric half-mask air-purifying respirators equipped with an organic vapor cartridge while performing routine work. Respirators should be worn until engineering or administrative controls are implemented to reduce TCE exposures below the NIOSH

3. Employees performing maintenance activities in the battery separator production areas should wear elastomeric full-face air purifying respirators equipped with an organic vapor cartridge because they may be exposed to TCE air concentrations above 250 ppm. This recommendation is based on results from shorter-term air sample results collected while employees were performing line maintenance in the battery separator production areas.

4. Employees should wear gloves made of polyvinyl alcohol, Teflon™, Viton™, or other suitable material when handling unfinished (i.e., "wet") battery separator material that contains a higher percentage of TCE than in the final product to minimize the potential for dermal exposure.

5. Employees should use hearing protection while working in any production area. Several employees were observed without ear plugs or muffs during this study. In addition, employees should be instructed to keep the volume of their personal radios to a minimum.

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Appendix A: Tables

Table A1. TCE Exposures, by Job, Shift, and Work Day

Start of Shift	Job/Activity	Line #	Shift	First half of shift Time	First half of shift TWA Conc	Second half of shift Time	Second half of shift TWA Conc	Full shift TWA Conc (ppm)
Sunday June 19, 2005	Winder	3	1	414	65	280	32	52
	Winder	1	1	395	84	299	30.	61
	Team Lead		1	376	65	304	21	45
	Winder	2	1	392	74	299	71	73
	Winder	4	1	385	69	232	56	64
	Extruder	8	1	375	66	325	18	44
	Rover	8	1	361	78	305	31	56
	Winder	8	1	374	69	317	45	58
	Extruder	7	1	393	63	284	39	53
	Maintenance		1	406	7.3	295	3.5	5.8
	Maintenance		1	394	28	285	24	26
	Maintenance		1	394	21	283	11	17
	Extruder	3	1	350	53	266	49	52
	Extruder	1	1	376	85	300	54	71
	Extruder	4	1	310	69	301	56	62
	Pelletizer		1	295	14	323	7.7	11
	Average				**57**		**34**	**47**
	Max				**85**		**71**	**73**
	Min				**7.3**		**3.5**	**5.8**
Sunday June 19 to Monday, June 20, 2005	Team Lead		2	377	120	309	36	82
	Team Lead		2	379	98	304	41	73
	Winder	3	2	387	60.	284	47	55
	Winder	8	2	414	83	259	42	67
	Winder	8	2	380	110	287	64	89
	Extruder	8	2	365	65	300	34	51
	Winder	2	2	388	62	281	40	52
	Pelletizer		2	410	13	266	10	12
	Utility		2	374	27	291	17	22
	Rover	2	2	147	69	295	38	48
	Extruder	7	2	364	100	297	39	73
	Winder	1	2	378	58	284	46	53
	Extruder	2	2	382	66	276	47	58
	Extruder	1	2	377	80	282	53	69
	Maintenance		2	391	35	277	2.3	22
	Maintenance		2	390	39	280	3.3	24
	Supervisor		2	356	97	172	100	98
	Winder	8	2	356	87	289	54	72
	Rover	8	2	369	72	264	40	58
	Average				**71**		**40**	**57**
	Max				**120**		**100**	**98**
	Min				**13**		**2.3**	**12**

Table A1. TCE Exposures, by Job, Shift, and Work Day

Start of Shift	Job/Activity	Line #	Shift	First half of shift Time	First half of shift TWA Conc	Second half of shift Time	Second half of shift TWA Conc	Full shift TWA Conc (ppm)
Monday, June 20, 2005	Winder	8	1	358	58	327	57	58
	Maintenance		1	391	11	299	3.1	7.3
	Extruder	8	1	348	38	355	27	32
	Extruder	8	1	398	44	281	36	41
	Team Lead		1	357	44	329	35	40.
	Winder	4	1	361	48	325	37	42
	Extruder	4	1	365	48	243	40.	45
	Winder	7	1	351	33	323	35	34
	Rover	8	1	343	40	321	56	48
	Utility		1	369	13	323	8.0	11
	Winder	3	1	357	46	320	35	41
	Cut-to-Size		1	370	6.4	319	3.0	4.8
	Winder	2	1	365	40.	313	33	37
	Extruder	1	1	364	36	320	37	37
	Extruder	2	1	356	58	320	48	53
	Pelletizer		1	337	8.9	332	0.20	4.6
	Extruder	3	1	347	31	314	32	32
	Maintenance		1	376	4.4	285	8.1	6.0
	Maintenance		1	378	5.1	292	12	8.0
	Supervisor		1	295	37	351	24	30
	Average				**32**		**28**	**30**
	Max				**58**		**56**	**58**
	Min				**4.4**		**0.02**	**4.6**

Table A1. TCE Exposures, by Job, Shift, and Work Day

Start of Shift	Job/Activity	Line #	Shift	First half of shift Time	First half of shift TWA Conc	Second half of shift Time	Second half of shift TWA Conc	Full shift TWA Conc (ppm)
Monday, June 20 to Tuesday, June 21, 2005	Team Lead		2	377	30.	303	17	24
	Supervisor		2	370	24	294	5.7	16
	Team Lead		2	373	39	306	18	30.
	Winder	4	2	382	29	301	24	27
	Extruder	8	2	389	34	289	19	28
	Winder	8	2	384	33	288	26	30
	Winder	8	2	379	33	280	20	27
	Rover	8	2	368	29	298	23	26
	Winder	8	2	378	41	289	22	33
	Winder	2	2	361	32	300	24	28
	Extruder	7	2	379	36	275	23	31
	Winder	3	2	372	33	298	25	30.
	Extruder	2	2	308	28	257	38	32
	Pelletizer		2	379	7.5	275	3.8	5.9
	Winder	1	2	356	30	293	24	28
	Utility		2	381	8.5	273	8.2	8.4
	Rover	2	2	399	12	249	11	12
	Maintenance		2	378	21	277	7.3	15
	Maintenance		2	384	20.	271	6.3	15
	Extruder	1	2	280	39	293	40	39
	Average				**28**		**19**	**24**
	Max				**41**		**40**	**39**
	Min				**7.5**		**3.8**	**5.9**
Tuesday, June 21, 2005	Winder	8	1	394	39	283	37	38
	Extruder	8	1	390	41	279	20	32
	Extruder	8	1	380	27	276	24	26
	Cut-to-Size		1	420	2.8	278	1.6	2.4
	Winder	4	1	398	28	291	33	30.
	Team Lead		1	404	30.	274	31	30.
	Extruder	1	1	342	31	284	32	31
	Extruder	4	1	400	38	284	34	37
	Utility		1	392	7.6	285	10	8.7
	Rover	4	1	378	35	291	32	34
	Maintenance		1	406	10.	272	6.0	8.5
	Winder	3	1	392	28	285	29	28
	Extruder	7	1	371	26	298	29	27
	Extruder	2	1	399	34	283	37	35
	Pelletizer		1	370	8.1	301	8.8	8.4
	Winder	2	1	385	24	291	24	24
	Extruder	3	1	392	35	286	37	36
	Maintenance		1	407	27	263	7.9	19
	Supervisor		1	372	19	305	20	19
	Maintenance		1	429	19	239	6.6	15
	Average				**25**		**23**	**24**
	Max				**41**		**37**	**38**
	Min				**2.8**		**1.6**	**2.4**

Table A1. TCE Exposures, by Job, Shift, and Work Day

Start of Shift	Job/Activity	Line #	Shift	First half of shift Time	First half of shift TWA Conc	Second half of shift Time	Second half of shift TWA Conc	Full shift TWA Conc (ppm)
Tuesday, June 21 to Wednesday, June 22, 2005	Rover	8	2	407	16	273	21	18
	Extruder	8	2	393	21	292	20	21
	Winder	8	2	385	24	292	24	24
	Winder	8	2	380	25	288	21	23
	Winder	3	2	373	0.0	234	34	13
	Team Lead		2	413	32	257	15	25
	Extruder	7	2	384	26	293	24	25
	Extruder	2	2	400	34	263	41	37
	Winder	7	2	378	25	292	24	25
	Winder	4	2	363	23	297	40	31
	Utility		2	369	8.1	289	9.6	8.7
	Winder	1	2	383	23	273	29	26
	Extruder	1	2	391	34	270	35	34
	Pelletizer		2	375	5.9	285	6.8	6.3
	Rewinder		2	363	12	284	14	13
	Supervisor		2	379	7.4	265	17	11
	Winder	2	2	375	21	275	20	21
	Maintenance		2	406	18	94	1.9	15
	Maintenance		2	317	17	223	4.5	12
	Team Lead		2	389	31	257	19	26
	Average				**20**		**21**	**21**
	Max				**34**		**41**	**37**
	Min				**0.0**		**1.9**	**6.3**

Table A1. TCE Exposures, by Job, Shift, and Work Day

Start of Shift	Job/Activity	Line #	Shift	First half of shift Time	First half of shift TWA Conc	Second half of shift Time	Second half of shift TWA Conc	Full shift TWA Conc (ppm)
Wednesday, June 22, 2005	Extruder	8	1 & 3	339	13	321	17	15
	Winder	8	1 & 3	184	17	321	24	22
	Maintenance		1 & 3	342	2.6	330	4.9	3.7
	Team Lead		1 & 3	320	21	309	16	18
	Rover	4	1 & 3	321	15	321	20	17
	Maintenance		1 & 3	312	5.4	301	5.6	5.5
	Extruder	4	1 & 3	319	3.6	299	35	19
	Extruder	1	1 & 3	315	27	325	38	33
	Winder	4	1 & 3	316	20.	326	24	22
	Extruder	3	1 & 3	316	39	329	34	36
	Utility		1 & 3	334	4.0	326	6.4	5.2
	Utility		1 & 3		No sample	323	16	16
	Extruder	7	1 & 3	327	17	331	26	22
	Winder	3	1 & 3	314	23	126	36	26
	Pelletizer		1 & 3	324	4.0		No sample	4.0
	Extruder	2	1 & 3	305	28	321	38	33
	Winder	2	1 & 3	305	17	324	22	20.
	Cut-to-size		1 & 3	369	2.9	310	0.8	2.0
	Supervisor		1 & 3	306	29	341	9.3	19
	Extruder	8	1 & 3	318	19		No sample	19
	Maintenance		1 & 3	297	6.2	318	5.7	5.9
	Maintenance				No sample	317	24	24
	Maintenance				No sample	309	29	29
	Average				**16**		**21**	**18**
	Max				**39**		**38**	**36**
	Min				**2.6**		**0.80**	**2.0**

Table A1. TCE Exposures, by Job, Shift, and Work Day

Start of Shift	Job/Activity	Line #	Shift	First half of shift Time	First half of shift TWA Conc	Second half of shift Time	Second half of shift TWA Conc	Full shift TWA Conc (ppm)
Wednesday, June 22 to Thursday, June 23, 2005	Team Lead		2 & 4	347	22	305	32	26
	Team Lead		2 & 4	419	23	256	39	29
	Rover	8	2 & 4	333	20.		No sample	20.
	Winder	8	2 & 4	330	26	324	30	28
	Extruder	8	2 & 4	198	16	328	27	42
	Winder	7	2 & 4	327	25		No sample	25
	Extruder	7	2 & 4	330	22	264	35	28
	Winder	8	2 & 4	409	23	266	29	25
	Supervisor		2 & 4	262	14	299	24	19
	Extruder	2	2 & 4	313	1.7		No sample	1.7
	Winder	4	2 & 4	317	22	267	38	29
	Extruder	1	2 & 4	458	40.		No sample	40.
	Winder	2	2 & 4	409	22	253	25	23
	Pelletizer		2 & 4	321	9.2		No sample	9.2
	Maintenance		2 & 4	323	5.2	301	7.4	6.3
	Maintenance		2 & 4	396	9.4	298	12	10.
	Utility		2 & 4	317	3.9		No sample	3.9
	Winder	1	2 & 4	291	23		No sample	23
	Winder	3	2 & 4	270	30.	264	37	34
	Winder	8	4	308	30.		No sample	30.
	Winder	8	4	289	30.		No sample	30.
	Winder				No sample	18	35	35
	Winder	2	4	210	34	17	47	35
	Extruder	3	4	286	43		No sample	43
	Extruder	4	4	283	40		No sample	40
	Average				**22**		**30**	**26**
	Max				**43**		**39**	**43**
	Min				**1.7**		**7.4**	**1.7**

Table A1. TCE Exposures, by Job, Shift, and Work Day

Start of Shift	Job/Activity	Line #	Shift	First half of shift Time	First half of shift TWA Conc	Second half of shift Time	Second half of shift TWA Conc	Full shift TWA Conc (ppm)
Thursday, June 23, 2005	Extruder	8	3	380	29	307	27	28
	Supervisor		3	433	22	279	29	25
	Rover	8	3	380	28	307	23	26
	Winder	8	3	390	31	298	25	28
	Winder	7	3	406	28	282	30	29
	Winder	8	3	386	31	302	25	28
	Winder	4	3	387	32	300	31	32
	Team Lead		3	394	34	276	31	33
	Rover	7	3	428	21	251	18	20
	Cut-to-size		3	411	3.5	286	2.3	3.1
	Utility		3	415	3.0	286	7.3	4.7
	Winder	2	3	413	28	277	30.	29
	Winder	1	3	390	28	301	27	28
	Extruder	4	3	405	28	288	31	29
	Extruder	1	3	385	41	299	44	42
	Extruder	3	3	380	34	297	35	35
	Extruder	2	3	382	38	299	32	36
	Utility		3	388	9.6	301	7.6	8.7
	Maintenance		3	393	17	285	18	18
	Maintenance		3	382	17	295	11	14
	Winder	3	3	386	37	286	39	38
	Average				**26**		**25**	**25**
	Max				**41**		**39**	**42**
	Min				**22**		**2.3**	**4.7**

Table A1. TCE Exposures, by Job, Shift, and Work Day

Start of Shift	Job/Activity	Line #	Shift	First half of shift Time	First half of shift TWA Conc	Second half of shift Time	Second half of shift TWA Conc	Full shift TWA Conc (ppm)
Thursday, June 23 to Friday, June 24, 2005	Rover	8	4	394	16	297	15	16
	Team Lead		4	377	29	289	26	27
	Team Lead		4	373	27	301	19	23
	Winder	8	4	380	28	303	23	26
	Winder	8	4	380	23	295	24	23
	Winder	4	4	393	35	282	32	34
	Extruder	8	4	384	29	293	24	27
	Winder	2	4	359	27	304	23	25
	Winder	8	4	374	31	298	20	26
	Extruder	3	4	361	39	302	37	38
	Winder	3	4	365	52	300	45	49
	Pelletizer		4	379	13	291	6.4	10.
	Extruder	1	4	353	50	320	35	43
	Extruder	7	4	367	27	294	22	25
	Extruder	4	4	347	40.	316	27	34
	Utility		4	352	17	307	11	14
	Maintenance		4	235	24	274	11	17
	Supervisor		4	339	22	305	18	20
	Winder	1	4	353	28	291	26	27
	Average				**29**		**23**	**27**
	Max				**52**		**45**	**49**
	Min				**16**		**6.4**	**10.**
Friday, June 24, 2005	Rover	8	3	382	27	327	45	35
	Winder	8	3	363	33	302	27	30
	Extruder	8	3	374	30	308	33	31
	Winder	8	3	383	32	383	23	28
	Winder	7	3	398	23	292	33	28
	Winder	4	3	382	28	308	29	29
	Team Lead		3	403	28	283	21	25
	Extruder	4	3	376	40	298	31	36
	Extruder	7	3	371	30	310	27	29
	Extruder	3	3	372	33	310	33	33
	Winder	2	3	385	26	306	24	25
	Extruder	2	3	377	44	307	41	43
	Winder	1	3	382	2.8	309	23	12
	Utility		3	383	9.0	311	7.9	8.5
	Utility		3	371	21	318	21	21
	Extruder	1	3	374	46	307	230	130
	Maintenance		3	376	12	305	9.4	11
	Winder	3	3	366	27	140	51	33
	Maintenance		3	354	20	268	15	18
	Maintenance		3	346	31	325	13	22
	Maintenance		3	369	27	290	14	22
	Average				**27**		**36**	**31**
	Max				**45**		**230**	**130**
	Min				**2.8**		**7.9**	**8.5**

Table A1. TCE Exposures, by Job, Shift, and Work Day

Start of Shift	Job/Activity	Line #	Shift	First half of shift Time	First half of shift TWA Conc	Second half of shift Time	Second half of shift TWA Conc	Full shift TWA Conc (ppm)
Friday, June 24 to Saturday, June 25, 2005	Winder	8	4	251	54	294	33	42
	Winder	8	4	382	37	292	37	37
	Winder	4	4	375	30	291	37	33
	Team Lead		4	386	29	277	35	32
	Winder	2	4	395	31	267	42	36
	Winder	3	4	370	29	289	34	31
	Extruder	7	4	384	32	285	33	32
	Team Lead		4	374	38	294	42	40
	Extruder	1	4	364	41	292	42	42
	Supervisor		4	359	25	306	29	27
	Winder	7	4	386	26	287	31	28
	Extruder	3	4	364	28	293	37	32
	Extruder	4	4	367	33	318	29	31
	Extruder	8	4	406	28	275	34	30
	Pelletizer		4	382	26	284	34	30
	Utility		4	356	6.0	292	6.9	6.4
	Maintenance		4	348	5.6	298	14	9.4
	Average				**29**		**32**	**30**
	Max				**54**		**42**	**42**
	Min				**5.6**		**6.9**	**6.4**
Saturday, June 26, 2005	Utility				No sample	310	7.2	7.2
	Utility		3	390	3.2	285	45	21
	Extruder	8	3	399	56	315	28	44
	Winder	7	3	368	32	290	51	41
	Rover	8	3	392	73	331	32	54
	Maintenance		3	343	41	337	26	34
	Team Lead		3	364	29	286	34	31
	Winder	8	3	399	62	318	29	47
	Winder	4	3	367	24	310	23	24
	Winder	2	3	378	22	318	34	27
	Pelletizer		3	360	34	315	3.6	20
	Extruder	3	3	365	29	318	36	32
	Winder	3	3	360	29	313	20	25
	Winder	1	3	370	21	314	40	30
	Extruder	1	3	366	35	310	28	32
	Extruder	4	3	362	28	312	43	35
	Extruder	2	3	366	34	318	27	31
	Utility		3	369	12	284	22	17
	Maintenance		3	372	52		No sample	52
	Average				**34**		**29**	**32**
	Max				**73**		**51**	**54**
	Min				**3.2**		**3.6**	**7.2**

Table A1. TCE Exposures, by Job, Shift, and Work Day

Start of Shift	Job/Activity	Line #	Shift	First half of shift Time	First half of shift TWA Conc	Second half of shift Time	Second half of shift TWA Conc	Full shift TWA Conc (ppm)
Saturday, June 26, 2005	Winder	2	4	362	20		No sample	20
	Winder	3	4	361	22		No sample	22
	Winder	8	4	378	22		No sample	22
	Extruder	7	4	375	24		No sample	24
	Team Lead		4	369	41		No sample	41
	Winder	4	4	368	24		No sample	24
	Extruder	3	4	359	27		No sample	27
	Winder	8	4	376	23		No sample	23
	Extruder	4	4	358	23		No sample	23
	Team Lead		4	374	28		No sample	28
	Pelletizer		4	350	8.8		No sample	8.9
	Extruder	8	4	366	32		No sample	32
	Maintenance		4	352	6.7		No sample	6.7
	Winder	7	4	380	23		No sample	23
	Supervisor		4	368	23		No sample	23
	Average				**23**			**23**
	Max				**41**			**41**
	Min				**8.9**			**8.9**

Table A2. Personal Noise Dosimeter Results

Date	Shift	Job	Sample Time (Hr:Min)	Dose %† OSHA PEL	Dose %† NIOSH REL	TWA in dBA‡ OSHA PEL	TWA in dBA‡ NIOSH REL
6/19/05	1	Extruder Line 1	11:08	11.8∗	191.6	74.6	87.8
6/20/05	1	Winder, Line 8	9:36	8.7	116.7	72.4	85.7
6/20/05	1	Winder, Line 3	9:32	5.7	67.8	69.4	56.8
6/20/05	1	Winder, Line 2	9:48	14.3	138	74.5	86.4
6/22/05	1	Cut-to-Size	9:09	2.8	93.5	64.2	84.7
6/21/05	1	Extruder, Line 8	10:13	5.6∗	139	69.2	86.4
6/21/05	1	Pelletizer	9:53	142.3∗	1166	92.5	95.7
6/21/05	1	Extruder, Line 7	9:46	76.7∗	8115	88.1	104.1
6/22/05	1	Supervisor	2:49	3.5	36.7	65.8	80.6
6/19/05	2	Forklift Operator	11:25	7.9	106.4	71.7	85.3
6/19/05	2	Extruder, Line 4	11:03	26.3∗	265.3	80.4	89.2
6/19/05	2	Regrind/Winder, Line 4	10:44	5.4	97.8	68.9	84.9
6/20/05	2	Extruder, Line 7	10:51	22.3∗	204	79.2	88.1
6/20/05	2	Team Lead	10:17	14.2	117.7	75.9	85.7
6/20/05	2	Maintenance	10:05	13.3	154.8	75.5	86.9
6/20/05	2	Winder, Line 8	11:08	9.1	364.3	72.7	90.6
6/20/05	2	Pelletizer	10:04	105.7∗	559.7	90.4	92.5
6/21/05	2	Rewinder	10:46	7.8	103.7	71.6	85.2
6/21/05	2	Supervisor	10:44	9.7	102.9	73.2	85.1
6/21/05	2	Extruder, Line 2	11:02	18.9∗	229.5	78	88.6
6/22/05	2	Maintenance	2:57	19.1	141.3	78	86.5
6/22/05	2	Extruder, Line 1	11:02	21.8∗	239.5	79	88.8
6/21/05	3	Winder, Line 8	11:12	30.7∗	276	81.5	89.4
6/22/05	3	Extruder, Line 8	3:05	3.4	40.4	65.7	81.1
6/22/05	3	Rover	3:10	26.9	259.4	80.5	89.1
6/22/05	4	Maintenance	4:56	10.5	102.1	73.8	85.1
6/22/05	4	Winder, Line 1	4:43	1.7	28.4	60.6	79.5
6/22/05	4	Winder, Line 8	5:33	17.5	193.4	77.4	87.9
6/22/05	4	Winder, Line 8	5:07	21	246.1	76.5	88.9
6/22/05	4	Team Lead	5:04	19.3	191.8	78.1	87.8
6/23/05	4	Winder, Line 4	11:11	3.0	84.4	64.7	84.3
6/23/05	4	Winder, Line 2	11:01	11.6∗	202.8	71.3	88.1
6/23/05	4	Extruder, Line 3	11:02	107.2∗	736.2	90.5	93.7
6/24/05	4	Team Lead	11:14	23.7∗	215.5	79.6	88.3
6/24/05	4	Pelletizer	11:06	154.4∗	754.7	93.1	93.8
		OSHA Permissible Exposure Limit		100		90	
		NIOSH Recommended Exposure Limit			100		85■

† The dose percentages are the amount of noise accumulated during a work day, with 100% representing the maximum allowable daily dose.
‡ Time weighted average of noise exposure levels during a sampling period, measured in A-weighted decibels.
∗ Exceeds the OSHA Action Level for noise.
■ Twelve-hour exposures have to be 83 dBA or less according to the NIOSH REL.

Trichloroethylene

Full-shift PBZ air samples for TCE were collected on the following jobs: extruders, winders, maintenance, rovers, utility, team leads, supervisors, pelletizer, and cut-to-fit. Shorter-term samples were collected to evaluate specific non-routine work tasks in the battery separator production area (such as a line break repair or during a product change). To verify that there was no TCE exposure to the non-exposed participants working in nearby offices and at Entek Manufacturing, GA air samples were collected at these locations throughout the week. Short-term PBZ air samples were collected to evaluate specific non-routine work tasks (such as a line break repair or during a product change over).

All full-shift PBZ and GA air samples for TCE were collected on activated charcoal tubes at a flow rate of 50 cc/min. Short-term air samples were collected at a flow rate of 100 cc/min. All sampling equipment was calibrated prior to use. The charcoal tubes samples were analyzed by gas chromatography according to NIOSH NMAM Method 1022 [NIOSH 2006].

Fresh urine samples were collected in sterile polypropylene specimen containers over a period of 6 days. One sample was collected from each study participant at the end of their workweek. At the time of collection, 1 mL of urine was transferred into empty 2 mL round bottom cryovials with a sterile transfer pipette. The aliquots, to be used for creatinine analysis, were then frozen, field-stored, and then shipped on dry ice. At the NIOSH laboratory, the samples were initially stored in a -70°C freezer while awaiting transfer to the Reproductive Endocrinology Laboratory where they were stored in a -80°C freezer.

The urine samples were analyzed for TCAA by a method developed by DataChem Laboratories, a NIOSH contract laboratory. The frozen urine samples were allowed to thaw. A 200 mL aliquot was removed, mixed with boron trifluoride/methanol (14%), and heated to 60°C for 2.5 hours. After cooling, 2 mL of toluene was added to each sample. The samples were then vortexed for 1 minute to separate the toluene layer, and the extract was dried by passing through a bed of anhydrous sodium sulfate. This extract was analyzed for TCAA using a Hewlett-Packard Model 5890 gas chromatograph equipped with an electrol capture detector and a 7673A autosampler.

For the urinary creatinine assay, samples were diluted 1:30 using a TECAN Robotic Sample Processor; duplicate dilutions were pipetted by the robot and each dilution analyzed in singlet using a Vitros 250 Chemistry Analyzer (Ortho-Clinical Diagnostics). Creatine, derived via a slow reaction from creatinine, is converted to sarcosine, which is then oxidized to yield peroxide, which in turn oxidizes leuco dye to yield a colored product. The change in reflectance measured between readings at 3.85 minutes and 5 minutes is proportional to the creatinine level in the sample, and readings are made at 37°C using 670 nanometer wavelength. Creatinine measurements were calibrated with a 3-level standard curve, with the highest value of 13 milligrams per deciliter corresponding to a concentration of 495 milligrams per deciliter for samples diluted 30-fold.

Noise

Quest® Electronics Model Q-300 Noise Dosimeters were worn by workers in the following job titles: extruders, winders, maintenance, rovers, utility, pelletizer, and cut-to-fit. The noise dosimeters were clipped to the employee's belt. A small microphone connected to the end of a cable attached to the noise dosimeter was fastened to the employee's shoulder halfway between the collar and the end of the employee's shoulder. A windscreen provided by the manufacturer was placed over the microphone during recordings. At the end of the employee's work shift the dosimeter was removed and paused to stop data collection. The information stored in the dosimeters was downloaded to a personal computer for interpretation with QuestSuite for Windows® software. All noise dosimeters were calibrated before and after use with a Quest CA-12B model calibrator according to the manufacturer's instructions.

Real time, instantaneous noise monitoring was done throughout Entek International production areas on June 24, 2005, with a Quest Electronics Model 2400 Type II SLM. The instrument was set to measure noise levels between 70 and 140 decibels, dBA. The SLM was calibrated before and after the measurement periods with a Quest CA-12B calibrator. Noise level readings were obtained three feet from each noise source.

Photo 2: Postural Sway Test

Neurobehavioral Testing

Postural Sway

Testing was performed on a microcomputer-controlled force platform using protocols established by NIOSH investigators [Dick 1995]. Four test conditions, each lasting 30 seconds, were used (e.g., eyes op and eyes closed on the hard platform and a foam pad). Each test condition was preceded by one practice trial. Prior to the sway testing, participants were instructed to remove their shoes and stand still on the platform, with arms at their sides focusing on a cross on a wall for the two conditions. Testing was repeated on the platform, with arms at their sides focusing on a cross on a wall for the two conditions. Testing was repeated with eyes closed, and standing on 4-inch thick foam pads, both with eyes open and eyes closed. Measures of sway area and sway length were used for analysis. Sway area represents the area within the sway path in square centimeters, and sway length is the length of the sway vector path in centimeters.

Photo 3: Visual Contrast Sensitivity Test Using FACT™ Chart

Visual Contrast Sensitivity

Contrast sensitivity testing was conducted using the FACT™ hand-held chart [Ginsburg 1993]. This instrument consists of a calibrated rod with a card holder at one end and cheek pads at the other end that is held tightly against the face to maintain a constant viewing distance between the eyes and the test card. The FACT™ sine-wave grating chart tests five spatial frequencies (A, B, C, D, and E) and nine levels of contrast. The last grating seen for each spatial frequency row, assessed by a correct reporting of the orientation of the grating (right, up, or left), is plotted on a contrast sensitivity curve. Test results produce a visuo-gram that indicates sensitivity at each of the five spatial frequencies (e.g., 1.5, 3, 6, 12, 18 cycles per degree) tested. The preprinted recording form indicates the normal range of average performance for 90% of the normal population [Ginsburg 1993]; separate norms for gender or age are not available. Because high levels of visual sensitivity for spatial form are associated with low contrast thresholds, a reciprocal measure (1/

threshold), termed the contrast sensitivity score, is computed. Measures of visual contrast sensitivity, rather than measures of refractory visual acuity, have been presented as better appraisals of visual dysfunction resulting from chemical exposures. However, if visual acuity is poor, then performance on the FACT™ will also be poor. Therefore we also measured visual acuity using a handheld Snellen chart. Results from persons with visual acuity of 20/40 or worse were removed from further analysis.

Photo 4: Grooved Pegboard Test

Grooved Pegboard Test

The Grooved Pegboard Test was used to assess fine psychomotor control as well as to evaluate visual, tactile, and kinesthetic motor systems. The test consists of a small board containing a 5 by 5 set of slotted holes angled in different directions. Subjects are seated in front of the pegboard and instructed to insert 25 pegs into the 25 holes as fast as they can, starting with their dominant hand. The time in seconds to complete the 25 insertions is recorded. After a short rest break, the non-dominant hand is tested. By examining both hands inferences may be drawn regarding possible lateral brain damage.

Trail Making A and B

The test consists of two parts, form A and form B. Form A consists of 8 consecutively numbered circles on one side of a sheet and 25 consecutively numbered circles on the other side. Form B consists of eight circles, four consecutively numbered and four consecutively lettered on one side of the sheet and 25 circles, 13 consecutively numbered (1–13) and 12 consecutively lettered (A–L) on the other side of the sheet. The subject is instructed to use a pencil to connect consecutively numbered circles on form A "as fast as you can without lifting the pencil from the paper," starting with the practice trial first. At the completion of the practice trial for form A, the sheet is turned over and the test begins. The test is timed, but the experimenter will interrupt to point out errors so the test is completed error free. Following completion of form A, form B is administered. In form B, subjects alternately connect (1-A-2-B-3-C and so on) numbered circles and lettered circles starting with the practice trial first. The test takes about 3 minutes and the number of correct circles and/or numbers connected within the time limit is totaled for each form (e.g., A and B). Adult age norms for forms A and B are available for comparison.

Symbol Color Recode Test

As shown in Photo 5, the Symbol Color RecodeTest presented one symbol at a time, using a Pentium® II-based Dell Latitude™ laptop personal computer, running Windows® 2000 Professional software. The Symbol Color Recode Test task involved pressing a matching colored button on a response pad, based on the pairings shown in the symbol color matrix, as quickly and accurately as possible using just the index finger of the preferred hand. The programming for the Symbol Color Recode Test was achieved by using SuperLab Pro version 2.0 Experimental Lab Software from the Cedrus® Corporation. Response input was coded from a six-key, color-coded, response panel available with the SuperLab Pro software. The arrangement of the colored response buttons on the panel mirrored that of the symbol color matrix. Test instructions were presented via the computer and were also paraphrased by the test administrators. Participants were queried to assure they understood the instructions, that they could distinguish the colors of the test, and that they were wearing corrective lenses if needed. Participants were given a short practice session with auditory feedback provided for incorrect responses. During the short practice, as well as the most of the 5-minute test session, the symbol-color matrix was always present above the symbol. However, another unique aspect of Symbol Color Recode Test task is that it tests the implicit learning that accompanies performance in tasks of this sort. This was achieved through a manipulation that instructed participants that the computer may determine, at some point during the test, that they have a sufficiently high level of performance and therefore remove the symbol color matrix from the screen. In actuality, the matrix was removed for every participant at the same point in the test, with the last 30 symbols being presented without the previously accompanying matrix.

Photo 5: Symbol Color Test

The Digit Symbol Test and the Symbol Digit Modalities Test present only a single number (digit symbol) or symbol (symbol digit), below the matrix and the participant must add the missing member of each pair, as quickly as possible with performance measured by the number of items correctly coded in a given time period (typically 90 seconds). In the Digit Symbol Test, motor performance is more challenging in that people have more practice writing numbers than symbols. While the motor component of the Digit Symbol Test would appear to make this a very different test than when the person writes numbers, the two tests correlate well. The Symbol Color Recode Test reduces the motor component of these tests, as well as any individual difference in digit writing proficiency, by pairing colors with symbols. Also, the Digit Symbol Test from the Wechsler Adult Intelligence Scale is typically administered as a paper-and-pencil test, while the Symbol Color Recode Test is completely computerized.

It was hypothesized that the frequently subtle effects of low-level chemical exposures on the nervous system may not have been evident in larger, more-overt test performance measures, but rather may be revealed in tests of higher cognitive functions such as implicit learning. It is important to note that the Symbol Color Recode Test has not, to date, been empirically validated.

References, Appendix B

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Appendix C: Occupational Exposure Limits & Health Effects

In evaluating the hazards posed by workplace exposures, NIOSH investigators use both mandatory (legally enforceable) and recommended OELs for chemical, physical, and biological agents as a guide for making recommendations. OELs have been developed by Federal agencies and safety and health organizations to prevent the occurrence of adverse health effects from workplace exposures. Generally, OELs suggest levels of exposure to which most workers may be exposed up to 10 hours per day, 40 hours per week for a working lifetime without experiencing adverse health effects. However, not all workers will be protected from adverse health effects even if their exposures are maintained below these levels. A small percentage may experience adverse health effects because of individual susceptibility, a pre-existing medical condition, and/or a hypersensitivity (allergy). In addition, some hazardous substances may act in combination with other workplace exposures, the general environment, or with medications or personal habits of the worker to produce health effects even if the occupational exposures are controlled at the level set by the exposure limit. Also, some substances can be absorbed by direct contact with the skin and mucous membranes in addition to being inhaled, which contributes to the individual's overall exposure.

Most OELs are expressed as a TWA exposure. A TWA refers to the average exposure during a normal 8- to 10-hour workday. Some chemical substances and physical agents have recommended STEL or ceiling values where health effects are caused by exposures over a short-period. Unless otherwise noted, the STEL is a 15-minute TWA exposure that should not be exceeded at any time during a workday, and the ceiling limit is an exposure that should not be exceeded at any time.

In the U.S., OELs have been established by Federal agencies, professional organizations, state and local governments, and other entities. Some OELs are legally enforceable limits, while others are recommendations. The U.S. Department of Labor OSHA PELs (29 CFR[*] 1910 [general industry]; 29 CFR 1926 [construction industry]; and 29 CFR 1917 [maritime industry]) are legal limits enforceable in workplaces covered under the Occupational Safety and Health Act. NIOSH RELs are recommendations based on a critical review of the scientific and technical information available on a given hazard and the adequacy of methods to identify and control the hazard. NIOSH RELs can be found in the *NIOSH Pocket Guide to Chemical Hazards* [NIOSH 2005]. NIOSH also recommends different types of risk management practices (e.g., engineering controls, safe work practices, worker education/training, personal protective equipment, and exposure and medical monitoring) to minimize the risk of exposure and adverse health effects from these hazards. Other OELs that are commonly used and cited in the U.S. include the TLVs recommended by ACGIH, a professional organization, and the WEELs recommended by the American Industrial Hygiene Association, another professional organization. ACGIH TLVs are considered voluntary exposure guidelines for use by industrial hygienists and others trained in this discipline "to assist in the control of health hazards" [ACGIH 2007]. WEELs have been established for some chemicals "when no other legal or authoritative limits exist" [AIHA 2007].

Employers should understand that not all hazardous chemicals have specific OSHA PELs, and for some agents the legally enforceable and recommended limits may not reflect current health-based information. However, an employer is still required by OSHA to protect its employees from hazards even in the absence of a specific OSHA PEL. OSHA requires an employer to furnish employees a place of employment free from recognized hazards that cause or are likely to cause death or serious physical harm [Occupational

* *Code of Federal Regulations.* See CFR in references.

Safety and Health Act of 1970 (Public Law 91–596, sec. 5(a)(1))]. Thus, NIOSH investigators encourage employers to make use of other OELs when making risk assessment and risk management decisions to best protect the health of their employees. NIOSH investigators also encourage the use of the traditional hierarchy of controls approach to eliminate or minimize identified workplace hazards. This includes, in order of preference, the use of: (1) substitution or elimination of the hazardous agent, (2) engineering controls (e.g., local exhaust ventilation, process enclosure, dilution ventilation), (3) administrative controls (e.g., limiting time of exposure, employee training, work practice changes, medical surveillance), and (4) personal protective equipment (e.g., respiratory protection, gloves, eye protection, hearing protection).
Safety and Health Act of 1970, Public Law 91–596, sec. 5(a)(1)]. Thus, NIOSH investigators encourage employers to make use of other OELs when making risk assessment and risk management decisions to best protect the health of their employees. NIOSH investigators also encourage the use of the traditional hierarchy of controls approach to eliminate or minimize identified workplace hazards. This includes, in order of preference, the use of: (1) substitution or elimination of the hazardous agent, (2) engineering controls (e.g., local exhaust ventilation, process enclosure, dilution ventilation), (3) administrative controls (e.g., limiting time of exposure, employee training, work practice changes, medical surveillance), and (4) personal protective equipment (e.g., respiratory protection, gloves, eye protection, hearing protection).

Trichloroethylene

TCE is a nonflammable, colorless liquid with a somewhat sweet odor and a sweet, burning taste. Short-term exposure to trichloroethylene causes irritation of the nose and throat and central nervous system depression, with symptoms such as drowsiness, dizziness, giddiness, headache, loss of coordination. High concentrations have caused numbness and facial pain, reduced eyesight, unconsciousness, irregular heartbeat, and death [NIOSH 1992].

The NIOSH REL for airborne TCE is 25 ppm for up to a 10-hour TWA exposure. However, since Entek International employees worked extended 12-hour shifts during this evaluation, the NIOSH REL was reduced by 25% to 21 ppm TWA. The OSHA PEL is 100 ppm, TWA for up to an 8-hour work shift, and no adjustment is made for extended work shifts [CFR]. The current ACGIH TLV for TCE (revised in 2007) is 10 ppm TWA for up to an 8-hour work shift [ACGIH 2007].

NIOSH does not have a recommended BEI for evaluating TCE exposures. However, measuring TCAA (a metabolite of TCE) in urine is one of several recommended biological determinants for evaluating TCE exposure, and is the best indicator of integrated exposure over the workweek [ACGIH 2005]. The current recommended ACGIH BEI for TCAA is 100 mg/g creatinine, and this value was intended to provide the same protection as the former TLV–TWA of 50 ppm. While the ACGIH TLV does not include a skin designation because significant systemic health effects resulting from skin exposure has not been demonstrated, dermal contact with liquid TCE can contribute to measured biological exposure [ACGIH 2005].

In 1995, the IARC classified TCE as a probable human carcinogen [Raaschou-Nielson et al. 2002]. Probable human carcinogenicity means that based on human carcinogenicity data there is limited evidence in humans for the carcinogenicity of TCE [IARC 1995]. To date, the data for the carcinogenicity of TCE in humans has been inconsistent and controversial [Raaschou-Nielson et al. 2002].

Noise

Noise-induced loss of hearing is an irreversible, sensorineural condition that progresses with exposure. Although hearing ability declines with age (presbycusis) in all populations, exposure to noise produces hearing loss greater than that resulting from the natural aging process. This noise-induced loss is caused by damage to nerve cells of the inner ear (cochlea) and, unlike some conductive hearing disorders, cannot be treated medically. While loss of hearing may result from a single exposure to a very brief impulse noise or explosion, such traumatic losses are rare. In most cases, noise-induced hearing loss is insidious. Typically, it begins to develop at 4000 or 6000 Hz (the hearing range is 20 Hz to 20000 Hz) and spreads to lower and higher frequencies. Often, material impairment has occurred before the condition is clearly recognized. Such impairment is usually severe enough to permanently affect a person's ability to hear and understand speech under everyday conditions.

The dBA is the preferred unit for measuring sound levels to assess worker noise exposures and is weighted to approximate the sensory response of the human ear to sound frequencies near the threshold of hearing.

The decibel unit is dimensionless, and represents the logarithmic relationship of the measured sound pressure level to an arbitrary reference sound pressure (20 micropascals, the normal threshold of human hearing at a frequency of 1000 Hz). Decibel units are used because of the very large range of sound pressure levels which are audible to the human ear. Because the dBA scale is logarithmic, increases of 3 dBA, 10 dBA, and 20 dBA represent a doubling, tenfold increase, and hundredfold increase of sound energy, respectively. It should be noted that noise exposures expressed in decibels cannot be averaged by taking the simple arithmetic mean.

The OSHA PEL for noise (29 CFR 1910.95) specifies a maximum of 90 dBA for 8 hours per day and uses a 5 dB time/intensity trading relationship, or exchange rate. This means that a person may be exposed to noise levels of 95 dBA for no more than 4 hours, to 100 dBA for 2 hours, etc. Conversely, up to 16 hours exposure to 85 dBA is allowed by this exchange rate. The duration and sound level intensities can be combined in order to calculate a worker's daily noise dose according to the formula, Dose = 100 X (C1/T1 + C2/T2 + ... + Cn/Tn), where Cn indicates the total time of exposure at a specific noise level and Tn indicates the reference duration for that level as given in Table G-16a of the OSHA noise regulation. During any 24-hour period, a worker is allowed up to 100% of his daily noise dose.

The OSHA regulation has an additional AL of 85 dBA; an employer shall administer a continuing, effective hearing conservation program when the 8-hour TWA value exceeds the AL. The program must include monitoring, employee notification, observation, audiometric testing, hearing protectors, training, and record keeping. All of these requirements are included in 29 CFR 1910.95, paragraphs (c) through (o). When workers are exposed to noise levels in excess of the OSHA PEL of 90 dBA, feasible engineering, or

administrative controls shall be implemented to reduce the workers' exposure levels.
The NIOSH REL for noise is 85 dBA as a TWA for 8 hours, 5 dB less than the OSHA standard. The NIOSH criterion also use a more conservative 3 dB time/intensity trading relationship in calculating exposure limits. Thus, a worker can be exposed to 85 dBA for 8 hours, but to no more than 88 dBA for 4 hours or 91 dBA for 2 hours. Since employees in this evaluation worked extended 12-hour work shifts, exposures have to be 83 dBA or less according to the NIOSH REL.

References, Appendix C

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Acknowledgements and Availability of Report

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