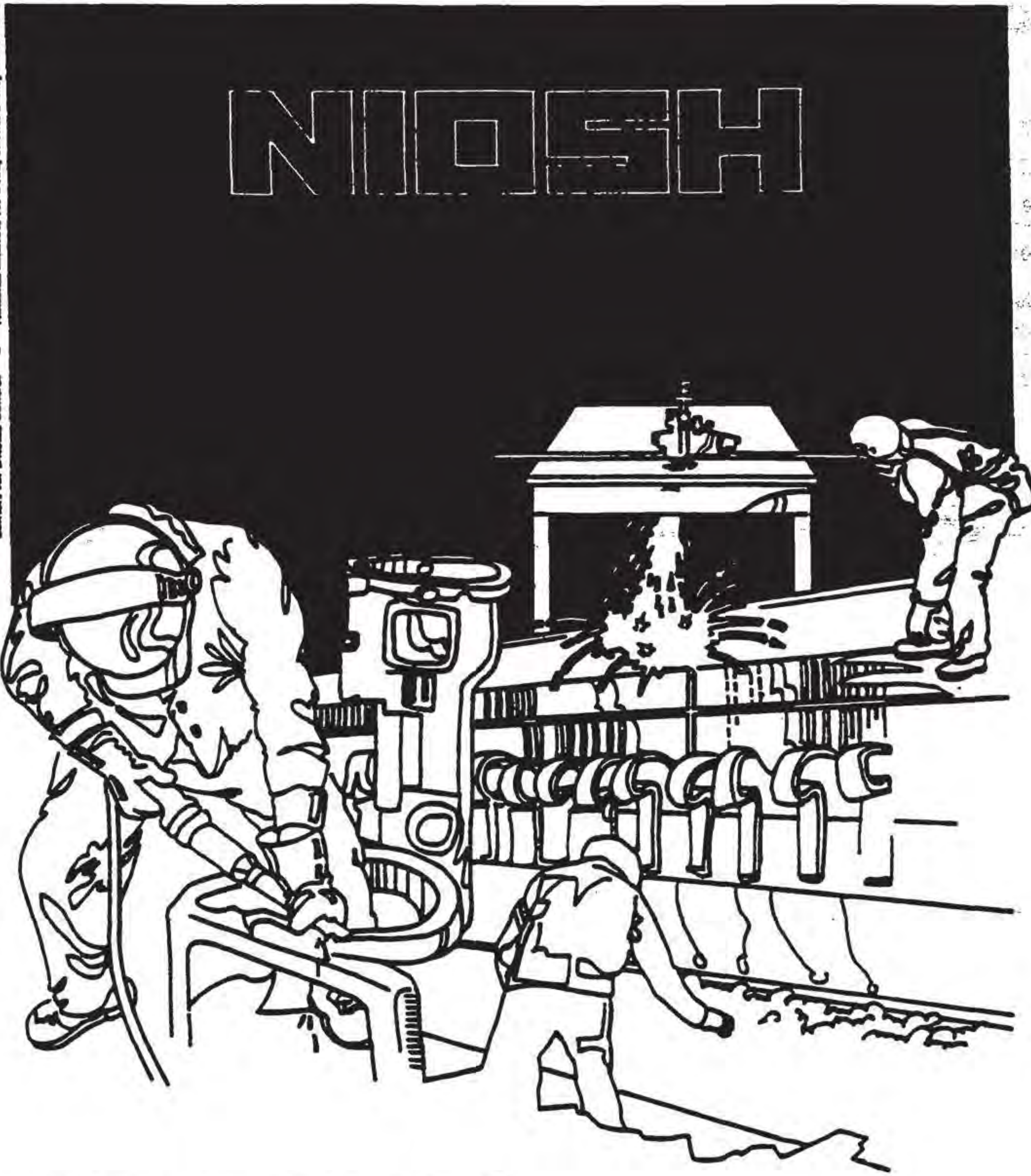
Centers for Disease Control ■ National Institute for Occupational Safety and Health



Health Hazard Evaluation Report

HETA 83-369-1672
LOCKHEED-GEORGIA COMPANY
MARIETTA, GEORGIA

PREFACE

The Hazard Evaluations and Technical Assistance Branch of NIOSH conducts field investigations of possible health hazards in the workplace. These investigations are conducted under the authority of Section 20(a)(6) of the Occupational Safety and Health Act of 1970, 29 U.S.C. 669(a)(6) which authorizes the Secretary of Health and Human Services, following a written request from any employer or authorized representative of employees, to determine whether any substance normally found in the place of employment has potentially toxic effects in such concentrations as used or found.

The Hazard Evaluations and Technical Assistance Branch also provides, upon request, medical, nursing, and industrial hygiene technical and consultative assistance (TA) to Federal, state, and local agencies; labor; industry and other groups or individuals to control occupational health hazards and to prevent related trauma and disease.

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I. SUMMARY

In July, 1983, the National Institute for Occupational Safety and Health (NIOSH) received a request to evaluate a potential health hazard in Building 84, at the Lockheed-Georgia Plant, Marietta, Georgia, where parts removed from C5A aircraft wings were being spray-cleaned with solvents (1,1,1-trichloroethane or a solvent blend known as Turco™ T-1000).

NIOSH investigators first visited Building 84 on August 18, 1983. Although solvent spray cleaning was done inside an exhaust ventilated booth, employees working near the booth and inspectors checking previously cleaned wing parts, complained that vapors from the booth, and residual solvents evaporating from the parts were causing headaches, coughing, burning eyes, sinus problems, and nausea. Analysis of bulk air samples taken in the breathing zone of the potentially exposed workers identified 1,1,1-trichloroethane, methylene chloride, tetrachloroethylene, diacetone alcohol, n-butanol, trimethyl benzene, 1,4-dioxane, acetone, indane, and xylene in the vapors released near the spray booth. Recommendations for further reducing solvent vapor exposures were made by NIOSH in an interim report issued September 16, 1983. To the extent feasible, these recommendations were implemented by Lockheed prior to a NIOSH follow-up survey at the plant on February 6-7, 1984.

During the follow-up epidemiologic study, quantitative personal air sampling detected low-level exposures to solvent vapors, but concentrations were well below NIOSH evaluation criteria. The highest exposures found were: 23 ppm 1,1,1-trichloroethane (350 ppm limit), 5.8 ppm methylene chloride (75 ppm limit), 2.8 ppm tetrachloroethylene (50 ppm limit*), 1.2 ppm aromatic hydrocarbons (as trimethyl benzene, 25 ppm limit), 0.2 ppm diacetone alcohol (50 ppm limit), 0.5 ppm n-butyl alcohol (50 ppm limit), and 0.2 ppm xylene (100 ppm limit). The exposures for the solvent sprayer during the follow-up survey were lower than expected, but only small wing parts were being sprayed.

Measurements of blood carboxyhemoglobin, total urinary trichloro-compounds and m-methyl hippuric acid were within or below normal levels in both exposed and unexposed workers, and no significant change across the work shift was noted in exposed workers.

* Note: NIOSH considers tetrachloroethylene (perchloroethylene) to be a suspect carcinogen and recommends exposures be reduced to the lowest technically feasible limit. The current exposure limit (ACGIH TLV) recommended for protection against effects on the central nervous system is 50 ppm. The OSHA Permissible Exposure Limit is 100 ppm.

To evaluate neurotoxic effects resulting from potential exposures to volatile organic compounds, a battery of neurobehavioral tests was administered to the seven exposed workers and to a comparison group of thirteen unexposed workers in another part of the plant.

Exposed workers performed worse than unexposed workers on the Bourdon-Wiersma test ($p=0.001$), a test of attention and alertness. Exposed workers also scored worse ($p=0.02$) than the unexposed workers on a Multi-Attention test. Because multiple comparisons were made, this latter result is of marginal statistical significance. Both these tests measured related functions (attention and alertness), suggesting there are real differences between the exposed and unexposed groups. Although these differences could reflect the chronic effects from previous solvent exposures in the exposed group's current or former jobs at the plant, an inadvertent study bias could also account for these differences.

There were no differences between exposed and unexposed workers in performance on tests of simple reaction time as determined from the Santa Ana Dexterity Test or the Wechsler Memory Scale. Comparisons between morning and afternoon performances of exposed and unexposed workers were unremarkable. This was not surprising because only low solvent vapor exposures were measured at the time of the testing. There were no statistically significant differences between the two groups of workers in the prevalence of neurologic or irritative symptoms.

No solvent exposures above NIOSH-recommended limits were detected during our visit. Differences in neurobehavioral performance between exposed and unexposed workers could not conclusively be attributed to solvent exposures received prior to the NIOSH site visit. Recommendations were made to maintain solvent exposures at low levels.

KEYWORDS: SIC 3721 (Aircraft Manufacturing), methylene chloride, 1,1,1-trichloroethane, tetrachloroethylene, solvents, central nervous system toxicity, neurobehavioral effects.

II. INTRODUCTION

On July 21, 1983, NIOSH received a request for a health hazard evaluation at the Lockheed-Georgia Plant in Marietta, Georgia. An authorized representative with the Aeronautical Machinists and Aerospace Workers, Lodge 709, asked NIOSH to investigate health hazards in Building 84, where reusable parts removed from C5A aircraft wings were being spray-cleaned with chlorinated hydrocarbon solvents inside an exhaust ventilated spray booth.

On August 18, 1983 a site visit was made to the plant to discuss the request and ensuing evaluation with company and union representatives, and to conduct a walk-through survey. NIOSH representatives observed the wing parts spray-cleaning procedures in Building 84, interviewed employees working in Building 84, measured the exhaust face velocity of the spray booth, and collected bulk air samples to determine the composition of the airborne vapors detectable in Building 84. An initial response letter with preliminary results from this survey was sent to Lockheed and Union representatives on September 16, 1983.

On February 6-8, 1984, NIOSH conducted a follow-up study to: (1) compare symptoms of neurologic and irritant effects of solvent exposure among solvent-exposed and comparable unexposed workers, (2) to objectively measure neurologic performance of the two groups, and (3) to collect air samples to measure individual personal exposures to solvent vapors from workers in each group. The air sampling results from this survey were forwarded to Lockheed and to the employee representatives on March 21, 1984.

III. BACKGROUND

The Lockheed-Georgia Company, in Marietta, Georgia manufactures military cargo aircraft for the U.S. Armed Forces as well as some foreign countries. The C130, C141, and C5A Aircraft were built at this plant. At the time of the NIOSH survey, C5A aircraft from the U.S. Air Force were being returned for new wings because of structural defects in the existing wings. All reusable components from the old wings were removed from the aircraft and brought to Building 84 (a 36,000 sq.ft. aircraft hanger).

To remove dirt and grease, the parts were loaded onto a cart and rolled into a large (16 feet high by 12 feet wide) exhaust ventilated spray booth where they were sprayed down with solvent. The spray booth was large enough to accommodate the C5A's wing flaps and ailerons. Only one worker did the spraying. When spraying, he wore a two-piece neoprene rubber rain suit, rubber gloves, boots, face shield, rubber hood, and a half-mask respirator with organic vapor cartridges. Although the booth was generally effective in capturing the solvent vapors released, personal protection was required because the worker spraying occasionally was required to stand between the part being sprayed and the exhaust slots at the rear of the booth. The solvent was pumped directly from a 55 gallon drum to a hand-held high pressure spray wand. Although most of the solvent spray evaporated, a sump pit under the booth collected any residual waste solvent or grease removed from the wing parts. After cleaning, the parts were rolled out of the booth for inspection. Parts found defective were repaired, pending Air Force approval.

About 34 drums of solvents were used each month. One of two degreasing solvents was used, Vulcan® Solvent 111 or Turco® T-1000. Turco® T-1000 was used on parts heavily coated with grease; otherwise, workers used Vulcan® Solvent 111. According to the suppliers, the solvents had the following compositions:

Solvent 111	98%	1,1,1-trichloroethane
	2%	1,4-dioxane (a stabilizer)
Turco T-1000	35%	perchloroethylene
	30%	methylene chloride
	25%	aromatic petroleum solvents
	5%	diacetone alcohol
	5%	n-butyl alcohol

Personal breathing zone air samples from the solvent sprayer, and area air samples from the face of the spray booth entrance were collected on activated charcoal tubes for later qualitative analysis by gas chromatography and mass spectrophotometry (GC/MS). Based on these analyses, 1,1,1-trichloroethane, methylene chloride, perchloroethylene, aromatic solvents (as trimethyl benzene), diacetone alcohol, n-butyl alcohol, and xylene were the organic vapors selected for further exposure monitoring.

Employees standing near the spray booth inspecting the cleaned aircraft parts complained that vapors from the booth, and residual solvent evaporating from the parts removed from the booth, were causing headaches, coughing, burning eyes, sinus problems, and nausea. Since these irritant and central nervous system effects were consistent with the known effects of exposure to solvent vapors, and because few controlled field studies of irritant, neurobehavioral effects of low-dose exposure to these common solvent mixtures had been done previously, NIOSH investigators decided to conduct a follow-up study. Our objective was to compare symptoms of neurologic and irritant effects of solvent exposure among solvent-exposed workers, with a comparison group of unexposed workers. This was accomplished by objectively measuring neurologic performance of the two groups and by quantitating personal exposures to the volatile organic compounds previously identified in the bulk air samples collected during the initial NIOSH survey.

IV. EVALUATION DESIGN AND METHODS

A. Environmental

In Building 84 on the morning of February 7th, 1984, five personal air samples and one area sample were collected when wing parts were spray cleaned with Turco™ T-1000 solvent. The samples were collected on activated charcoal tubes using pre-calibrated battery powered vacuum pumps. The methods used for sampling and analysis of the volatile organics contained in Turco™ T-1000 are summarized below.

ANALYTES	SAMPLE PUMP FLOW RATE	ANALYTICAL METHOD	REFERENCE
methylene chloride	0.02 Lpm	Gas Chromatography	NIOSH Method S-329[1]
tetrachloroethylene	0.1 Lpm	Gas Chromatography	NIOSH Method 127[2]
Aromatic solvents (as trimethyl benzene)	"	"	"
xylene	"	"	"
n-butyl alcohol	0.1 Lpm	Gas Chromatography	NIOSH Method S-66[3]
diacetone alcohol	"	"	"

Note: Lpm = liters of air per minute

During the afternoon of February 7th, an additional seven personal air samples and one area air sample were collected when wing parts were being cleaned with Vulcan™ Solvent 111. The samples were collected on activated charcoal tubes using pre-calibrated battery powered vacuum pumps set for a sample collection flow rate of 0.1 Lpm. The samples were analyzed by gas chromatography using NIOSH Method S-328.[4]

To verify that the unexposed comparison group of workers used as controls were not exposed to solvents, personal air samples were collected from each plant location where these workers were assigned. The samples were collected and analyzed for the volatile organics sampled in Building 84. These locations were also monitored qualitatively by collecting bulk air samples on charcoal tubes for later analysis by GC/MS to identify possible exposures to other volatile organic compounds.

B. Medical

The study population consisted of seven solvent-exposed workers in Building 84, and 13 other workers selected from production areas in other parts of the plant having no solvent exposure. Each "nonexposed" worker chosen had the same sex, race, and age (within five years) as a particular exposed worker. This resulted in 1-3 "nonexposed worker(s)" for each exposed worker. Of the eight solvent-exposed workers, seven agreed to participate in the study. Workers for the control group were first selected by factors of sex, age, and race from personnel lists of shipping and receiving workers. However, after the NIOSH representatives met with these workers to explain the study, only three of the 14 workers selected agreed to participate. To complete the study, eight male comparison workers were selected from the tool design area, where all but one eligible control agreed to participate. Two "nonexposed" female steno clerks also agreed to participate. Altogether, NIOSH found thirteen control workers to participate in the study. In each of the control work areas there was little possibility for solvent exposure.

The solvent-exposed workers included the solvent sprayer who worked inside the booth, various inspectors of cleaned parts, and two structural repairmen who worked in one corner of Building 84. The structural repairmen worked in an area furthest from the spray booth but they also used a small amount of methyl ethyl ketone in their jobs.

Demographic characteristics of exposed and "not-exposed" workers are described in Table 1. There were fewer black workers in the "not-exposed" group (23%) than in the exposed group (43%). The exposed workers were 3.6 years older than the "not-exposed".

All participating workers were administered a questionnaire. Prevalence of mucous membrane and respiratory irritation symptoms was determined. A questionnaire, widely used clinically and epidemiologically in evaluating solvent-exposed workers in Sweden[5], was used to assess neurobehavioral symptom prevalence.

Exposures were assessed by environmental monitoring (as described above) and by biological monitoring of total urinary trichloro-compounds and blood carboxyhemoglobin. Upon arriving at work and again in the afternoon after completing the neurobehavioral testing session, each exposed worker submitted a blood and urine sample and each "not-exposed" worker submitted a urine sample. The following biological measurements were made:

SOLVENT	BIOLOGICAL METABOLITE
Perchloroethylene Methyl chloroform	Total urinary trichloro- compounds analyzed colorimetrically by the method of Tanaka and Ikeda)[6]
Xylenes	Urinary m-methyl hippuric acid (by high pressure liquid chromatography using a modification of NIOSH Method 8301)[7]
Methylene chloride	Carboxyhemoglobin (exposed workers only --determined on Instrumentation Laboratories co-oximeter)

Perchloroethylene is metabolized to trichloroacetic acid, which is excreted in the urine. A one week exposure to perchloroethylene at the permissible exposure limit of 100 ppm is reported to produce 10 mg of trichloroacetic acid/gram creatinine in the urine. 1,1,1-Trichloroethane is metabolized to (and renally excreted as) both trichloroacetic acid and as trichloroethanol. In this study NIOSH measured total trichloro- compounds to reflect the combined exposure to 1,1,1-trichloroethane and perchloroethylene. Exposures to 1,1,1-trichloroethane at the recommended NIOSH limit of 350 ppm would likely produce less than 50 mg/gm creatinine total trichloro- compounds after one shift's exposure.[8] Xylene is metabolized to methyl hippuric acid. Carboxyhemoglobin is a metabolite of methylene chloride. The normal carboxyhemoglobin range for non-smokers is 0.5 - 2.0%. For smokers, the normal range is less than 12.0%.

C. Neurobehavioral Tests

To assess neurologic performance objectively, all workers were administered a battery of neurobehavioral tests:

Simple Reaction Time Test: This is a test of speed of response using two buttons. The subjects' task was to press button 1 until button 2 lighted, then release button 1 and press button 2 as rapidly as possible. Data collected were measures of release time (from button 1) and response time to push button 2 (in milliseconds). There were 50 trials, but the first 17 trials were discarded to account for the rapid improvements in speed that normally occur from practice. The first 17 trials included all release times slower than 750 milliseconds (msec) and all response times slower than 500 msec, our recommended maxima for these types of data.

Santa Ana Test: This test of eye-hand coordination utilizes four rows of pegs in square holes. The subject's task was to rotate (180 degrees) as many pegs as possible in the 30 seconds allowed. The total number of pegs rotated was the measured score.

Wechsler Memory Scale Test: In this test of short-term memory, two stories were read (using a tape recording) to the subjects. Participants were asked to recall all the facts they could at the end of each story. The data were the mean number of discrete memories from the two stories.

Multi-Attention Task: This task of attention and alertness presented three columns of symbols on a video display screen. The subject's task was to identify symbols that differed (the distractors) from those that were expected. In the test, three columns were displayed with the headings 7, 8, and 9. Under columns 7 and 9, 3x4 mm asterisks appeared at vertical intervals of 5 mm. Occasionally, pluses of the same size appeared, which were the distractors. The middle column, labelled 8, contained 3x4 mm numbers, also 5 mm apart, and the distractors here were 3x4 mm letters. At the beginning of the test, a single symbol appeared in each column, so that a row of 3 symbols (e.g., asterisk, number, asterisk) was presented, followed shortly thereafter by the next row, and so forth. The subject pushed one of three keyboard buttons labelled 7, 8, or 9 to indicate where a distractor appeared on the screen. There were either none, one, or two distractors per row, requiring no response, a one-button press, or a two-button press for any given row. Generally, there were no distractors in a given row. The screen blanked after ten rows appeared and a new "screen" of ten rows were presented in the same fashion. Ten separate or unique "screens" were presented and each screen was repeated two times for a total of 30 screens. The speed at which each succeeding row appeared began at 1400 msec between row presentations and progressed to 1200 and then 800 msec (10 1/2 screens or 10 screens plus 5 rows of the 11th screen at 1400 msec, 10 screens at 1200 msec, and 9 1/2 screens at 800 msec). Data collected were the number of differing symbols or distractors correctly detected by the subject at the three different speeds of presentation.

Bourdon-Wiersma Test: Sustained attention, or vigilance, and rapid hand movements were required for this test. The participant was given a sheet of paper containing 400 sets or groupings of 3, 4, or 5 dots and told to cross out as many sets of 4 dots as possible in 8 minutes. Each set of dots occupied an area of roughly 4 mm, and the sheet was organized in rows of 50 sets with 2 mm between sets and 4 mm between rows. The number of sets of 4 dots crossed out was recorded for each subject.

All tests were administered to each subject in the morning and again in the afternoon of the same day. Only two subjects could be tested at any one time; therefore, workers were tested at half hour intervals throughout the morning and again in the same order in the afternoon. About five hours separated the tests for each worker.

Differences between prevalence of various symptoms among exposed and matched "non-exposed" workers were analyzed using conditional logistic regression for matched case-control studies (Cox proportional hazard model for one case per matched set).[9]

Neuroperformance data from 20 subjects were collected. The three females (1 exposed and 2 unexposed) were not analyzed because of the small number, and the expectation that data from males and females could not be combined in a single analysis. Of the remaining subjects, three solvent-exposed workers were white and three were black. Seven unexposed subjects were white and four were black. The mean age was 48.8 for the exposed subjects and 44.9 years for the unexposed. The M-RANK nonparametric procedure was used to compare performance between exposed and control participants.[9] To be as sensitive as possible to potential differences in this exploratory analysis, each comparison was undertaken as an independent analysis. NIOSH evaluated acute effects among solvent-exposed workers by comparing morning with afternoon performance on the neurobehavioral test battery. In addition, afternoon performance in exposed vs. control workers was compared to assess possible chronic effects of solvent exposure.

V. EVALUATION CRITERIA

A. Environmental Criteria

As a guide to the evaluation of the hazards posed by workplace exposures, NIOSH field staff use environmental evaluation criteria for assessment of many chemical and physical agents. These criteria are intended to suggest levels of exposure to which most workers may be exposed up to 10 hours per day, 40 hours per week for a working lifetime without experiencing adverse health effects. However, not all workers will be protected from adverse health effects 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, 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 evaluation criterion. These combined effects are often not considered in the evaluation criteria. Also, some substances are absorbed by direct contact with the skin and mucous membranes potentially increasing the total exposure. Lastly, evaluation criteria may change over the years as new information on the toxic effects of an agent becomes available.

The primary sources of environmental evaluation criteria for the workplace are: (1) NIOSH criteria documents and recommendations, (2) the American Conference of Governmental Industrial Hygienists' (ACGIH) Threshold Limit Values (TLVs),[10] and (3) the U.S. Department of Labor (OSHA) occupational safety and health standards.[11] Often, the NIOSH recommendations and ACGIH TLVs are lower than the corresponding OSHA standards. Both NIOSH recommendations and ACGIH TLVs usually are based on more recent information than are the OSHA standards. The OSHA standards also may be required to take into account the feasibility of controlling exposures in various industries where the agents are used; the NIOSH-recommended standards, by contrast, are based solely on concerns relating to the prevention of occupational disease. When considering the exposure levels and the recommendations for reducing these levels found in this report, it should be noted that employers are legally required to meet only those levels specified by an OSHA standard.

The various criteria proposed by OSHA, ACGIH, and NIOSH for the airborne concentrations of the volatile organic compounds measured in this evaluation are listed in Table 2. A time-weighted average (TWA) exposure refers to the average airborne concentration of a substance during a normal 8- to 10-hour workday. Some substances have recommended short-term exposure limits (STEL) or ceiling values which are intended to supplement the TWA where there are recognized toxic effects from high short-term exposures.

For the purposes of this evaluation, NIOSH has selected the most stringent exposure limits as our evaluation criteria. The major health effects anticipated for workers exposed above these evaluation criteria are summarized in Table 2. A further discussion on the toxicity of several of the volatile organic compounds evaluated in this study is presented below.

1. **Acute Affects from Solvent Vapor Exposures**

Perchloroethylene is an eye irritant at 50-100 ppm.[12] 1,1,1-Trichloroethane is reported to have an objectionable odor at 350 ppm.[12] Transient eye irritation has been reported at 500 ppm.[13] Methylene chloride is a potent skin and eye irritant.[12] Trimethyl benzene, xylene, n-butyl alcohol (n-butanol), and diacetone alcohol are also respiratory or eye irritants at concentrations near the TLV.[12]

2. Methylene Chloride

Methylene chloride vapor is rapidly adsorbed via the lungs. At exposures normally encountered in industrial settings most of the methylene chloride is metabolized by the body to form carbon monoxide and probably carbon dioxide. Inhalation of methylene chloride is known to elevate carboxyhemoglobin levels.[12] This may pose a significant risk to patients with pre-existing cardiovascular disease. NIOSH recommends a time-weighted average (TWA) exposure limit to methylene chloride of 75 ppm to maintain carboxyhemoglobin levels below 5% in non-smokers.[14] Methylene chloride may also impair central nervous system function at higher exposure concentrations. Methylene chloride is a mutagen, and there is some evidence that it may be an animal carcinogen. There is equivocal evidence of teratogenic effects as well.[15]

Results recently published from a two-year inhalation study where mice and rats were exposed up to 4 times a day to methylene chloride at concentrations 2-4 times above the OSHA PEL have demonstrated that methylene chloride can produce lung and liver cancers in mice and benign tumors in the mammary glands of rats. These effects were not observed at the lower concentrations.[16] Methylene chloride therefore fits OSHA's definition as a potential carcinogen. A NIOSH "Current Intelligence Bulletin" (CIB) is now being prepared which will address these recent findings.

3. Tetrachloroethylene

In addition to its more frequently noted effect on the nervous system, causing dizziness, headache, vertigo, or light narcosis, the International Agency for Research on Cancer (IARC) has concluded that tetrachloroethylene (perchloroethylene) should be regarded as a suspect carcinogen based on tests with laboratory animals.[17] The results from a 1985 National Toxicology Program study have demonstrated a carcinogenic potential from inhalation of perchloroethylene in both sexes of mice and in male rats[18] In light of these results, perchloroethylene may be reclassified from a possible to a probable human carcinogen.[19] NIOSH currently recommends this substance be handled in the workplace as a potential human carcinogen.[20]

4. 1,1,1-Trichloroethane

1,1,1-Trichloroethane is irritating to the eyes on contact. Exposure to the vapor depresses the central nervous system. Symptoms include dizziness, incoordination, drowsiness, and increased reaction time. Unconsciousness and death can occur from exposure to excessive concentrations.[21] A few scattered reports have indicated mild kidney and liver injury in humans from severe exposure; animal experiments have confirmed the potential for liver, but not for kidney injury. Skin irritation has occurred from experimental skin exposure to the liquid and from occupational use.[22] Because of its structural similarity to other chloroethanes which cause cancer in animals, 1,1,1-trichloroethane is being evaluated for carcinogenicity.

5. 1,4-Dioxane

Present as a chemical stabilizer in Vulcan® Solvent T-111 (98% 1,1,1-trichloroethane and 2% 1,4-dioxane), dioxane is a suspect carcinogen, and NIOSH recommends reducing exposures to carcinogens to the lowest technically feasible level. Exposures should not exceed 1 ppm for a 30-minute exposure duration, the lowest level of detection by current sampling and analytical methods.[23]

VI. RESULTS

A. Environmental

Solvent vapor exposures monitored in Building 84, during spraying of C-5A wing components, were below levels which would be expected to cause adverse health effects for Lockheed employees working near the spray booth. The results presented in the Tables 3 and 4 represent the average concentrations for the duration of the sampling period. The solvent sprayer's TWA exposures to airborne solvent vapors were below NIOSH recommended limits but considerable time during his sampling period did not involve actual spraying. The sprayer would likely have higher short term exposures during spraying, especially when spraying the very large wing components such as wing flaps and aileron. The sprayer was therefore required to wear personal protective clothing and NIOSH approved respiratory protection when working in the spray booth.

As presented in Table 3, exposures to the components of Turco T-1000 fell within the following ranges:

TURCO T-1000 COMPOSITION	EXPOSURES DETECTED (ppm)	EXPOSURE LIMIT
30% methylene chloride	ND - 5.7	75 ppm
35% perchloroethylene	0.2 - 2.8	50 ppm*
25% aromatic solvents	0.1 - 1.2	25 ppm**
5% diacetone alcohol	ND - 0.2	50 ppm
5% n-butyl alcohol	ND - 0.5	C 50 ppm
(trace) xylene	ND - 0.2	100 ppm

C = ceiling limit
* Potential carcinogen - exposures should be reduced to the lowest technically feasible limit (LTFL)
** as trimethyl benzene

Table 4 shows the level of exposures during use of Vulcan® Solvent 111. This solvent contains 98% 1,1,1-trichloroethane. TWA exposures in building 84 during the period of application ranged from 0.5 - 23 ppm. The NIOSH recommended exposure limit for 1,1,1-trichloroethane is 350 ppm.

Except for the Tool Design area, only trace amounts of solvents (typical ambient air background levels) were detected on bulk air samples collected in "non-exposed" control areas. A small concentration of normal-hexane (about 0.1 - 0.2 ppm) was found in the tool design area, and one Tool Designer, selected as a control subject, was exposed to 0.7 ppm xylene. Although these were insignificant concentrations when compared to the recommended occupational exposure limits for n-hexane (50 ppm) and xylene (100 ppm), the finding does imply that subjects selected as controls from the Tool Design area were not completely free of solvent vapor exposures in their work areas. The source of these exposures were not specifically identified but they may come from aerosol spray adhesives used to hold down mechanical drawings.

The results from the bulk air samples collected for identification of any volatile organic compounds present in Building 84 and in the work locations of the selected "non-exposed" comparison group are presented below. Only the volatile organic compounds estimated to have the highest airborne concentration are listed. In all areas sampled the airborne concentration of any volatile organic compound identified was less than 0.3 ppm.

AREA SAMPLED	VOLATILE ORGANICS IDENTIFIED	ESTIMATED CONCENTRATION
Building 84	1,1,1-trichloroethane perchloroethylene	0.03 - 0.07 ppm 0.04 - 0.08 ppm
Building 83	1,1,1-trichloroethane	0.03 - 0.07 ppm
Tool Design	C_6 alkanes i.e.: methylpentanes hexane methylcyclopentane cyclohexane	0.1 - 0.2 ppm
Materials Receiving	toluene	<0.02 ppm
Traffic Office	toluene	0.05 ppm
Paint Stores (rec. & insp.)	toluene	0.15-0.25 ppm

B. Medical

Two of the seven workers exposed to solvents complained of previous episodes of headache, nausea, lightheadedness, and lethargy associated with heavy use of solvents in the spray booth. Symptoms subsided on weekends, and were worse when large parts requiring large volumes of solvent were being cleaned. None of the symptoms evaluated in the questionnaire survey were statistically significantly more prevalent in either the exposed or the unexposed group (See Table 5). However this is not surprising, considering the small sample size, where only a large proportional difference in symptom prevalence would be detected by a questionnaire survey.

Only normal amounts of blood carboxyhemoglobin and urinary total trichloro- compounds were detected on the day of the sampling (except for one worker who had an elevated carboxyhemoglobin level that was unchanged over the work shift and probably caused by smoking). Among the exposed non-smoking workers who submitted blood samples, the average pre-shift carboxyhemoglobin was 1.6% (range 1.3 - 2.0), and mean post-shift carboxyhemoglobin was also 1.6% (range 1.2 - 2.1). There was no increase between average morning and afternoon values in either the exposed or unexposed group for either of the two indices of absorption ($p > .05$ by student's t-test). Pre-shift mean total urinary trichloro-compounds were 0.2 mg/g creatinine (range 0 - 0.8) for exposed and 0.4 mg/g creatinine (range 0 - 2.6) for unexposed. Post-shift exposed workers had average urinary trichloro- levels of 0.3 mg/g creatinine (range 0 - 1.2). Neither differences across the shift nor differences between exposed and unexposed workers were significant ($p > 0.05$ by student's t-test). In all workers, urinary m-methyl hippuric acid was not detectable.

These results are consistent with the low levels of exposure measured in air samples. However, workers commented that solvent exposures were probably lower than normal at the time of our visit because only small parts were being sprayed. Also, outside temperatures were sub-freezing, and the solvents may have volatilized to a lesser extent than would occur in warmer weather.

C. Neurobehavorial Test Results

Based on the air and biological monitoring results presented above, it would be surprising to find acute differences (over the course of the work shift) in the neurobehavioral performance of exposed and unexposed workers. However, it is possible that over several months, under a more normal solvent spray cleaning schedule, worker exposures to higher concentrations of airborne solvents may have caused chronic impairment of neurobehavioral function, which would be reflected in differences in performance between exposed and unexposed workers (see Table 6).

1. Simple Reaction Time

Response times in milliseconds (msec) are presented in Table 6. The times from the onset of the light in the response button to release of the first button (release time), measured during near the start of the workshift, averaged 329 msec for the unexposed controls and 338 msec for the exposed workers. The times from release of the first button to press of the second response button (response time) averaged 185 msec for the preshift unexposed control subjects and 212 msec for the exposed group. Although the exposed were slower in most but not all cases, the differences did not approach statistical significance.

2. Santa Ana Test

The average number of pegs turned ranged from 17 to 19 for the two groups. Because of an error in the data storage program, data were not recorded in the morning for the exposed workers. The differences between unexposed and exposed workers in the afternoon were not significant, although exposed workers turned more pegs than the unexposed workers.

3. Wechsler Memory Scale

Both exposed and unexposed workers respectively remembered an average of 1.5 and 1.6 more facts in the afternoon than in the morning. This was expected, as the subjects were read the same stories in the afternoon as in the morning. The unexposed subjects remembered more discrete facts than the exposed, both in the morning (7.8 vs. 5.8) and the afternoon (9.3 vs. 7.4), but the differences were not significant.

4. Multi-Attention Task

The unexposed subjects identified a larger mean number of distractors (29 & 29) during the test than did the exposed (27 & 24), and the difference was significant in the afternoon (p=0.02).

5. Bourdon-Wiersma

Unexposed subjects improved from morning to afternoon (261 vs. 274), but exposed subjects performed better in the morning than in the afternoon (226 vs. 222). Group differences between exposed and unexposed were highly significant in the afternoon (p=0.001) when the unexposed correctly identified 35 more sets than the exposed (261 vs. 226), and in the afternoon when unexposed subjects identified 52 more than those exposed (274 vs. 222) (p=0.001).

VII. DISCUSSION

Both the Bourdon-Wiersma and the Multi-Attention Task reflect attention and alertness. The significant differences between exposed and nonexposed workers for these two tests, which measure similar or related functions, might suggest there were true differences in attention and alertness between the two groups. However, the group differences in the multi-attention task (p=.02) must be viewed with some skepticism, because the large numbers of comparisons made in this study can result in occasional spuriously statistically significant associations. Although the Bourdon-Wiersma tests, showed a cross-shift improvement in performance for the unexposed group (+13) and a cross-shift decline (-4) for the exposed group (p=.04), the low solvent vapor concentrations detected during the shift when these tests were given, indicate that test performance difference in the two groups was probably a spuriously significant association owing to the large numbers of comparisons made. There were no statistically significant differences between groups (either in the morning or across the shift) in any of the other performance tests.

The tests selected for this investigation were sensitive to the effects of exposure for the chemicals studied, but the small number of people tested made it unlikely that clear exposure effects would be identified unless the effects were relatively large. To counter this, as indicated above, the type of data analysis was essentially exploratory, treating each test as an independent case, which increased the chances of finding statistically significant effects.

Group differences have been seen in four other worksite studies which utilized the Bourdon-Wiersma. Viscose rayon workers exposed to carbon disulfide,[24,25,26] polyester plastics workers exposed to styrene,[27] and jet engine workers exposed to jet fuel[28] all showed poorer performance on this test, as compared to unexposed comparison subjects. A reduced ability to maintain attention or alertness in the types of tests used here would suggest concern for the safety of persons so-exposed and working with potentially dangerous machinery, or when driving home.

Both the acute symptoms described anecdotally by some workers during past exposures to solvents and the results of the performance testing suggest that there may be a causal relationship. The association is consistent with other studies demonstrating both acute and chronic central nervous system sequelae to solvent exposure. The principle solvents used in Building 84 have been shown to produce acute performance decrements in subjects exposed to levels near the TLV. Decrements in reaction time, perceptual speed and manual dexterity[29] and in balance (positive Romberg test) have been seen in persons exposed to 1,1,1-trichloroethane.[30] Exposure to perchloroethylene at 100 ppm has been shown to produce performance decrement in coordination.[31] Exposures to enough methylene chloride to produce carboxyhemoglobin levels approaching the recommended biological action level (5%) have been shown to produce acute decreases in the speed and precision of psychomotor performance.[32] Chronic methylene chloride exposure has been reported to affect neurologic function in animals[15], and high exposures have been reported anecdotally to cause chronic toxic brain damage in humans.[33]

Cross-sectional studies suggest that chronic exposure to solvents may have serious effects on neuroperformance.[34] Other studies suggest a strong association between solvent-exposure and disease. A case control study of Scandanavian patients with neuropsychiatric disease suggested that previous solvent exposure may account for up to 3% to 4% of all such disease.[35,36] It was estimated that among solvent exposed patients, nearly 1/2 of all such disease was caused by a previous solvent exposure history.[35]

There is some evidence that a synergistic effect occurs from exposures to certain organic vapor mixtures, meaning that a solvent mixture may be more neurotoxic than its individual components, resulting in impaired performance even where exposures are well below the TLV.[36,37] Based on this and other evidence, clinical neuro-psychiatric disorders resulting from solvent exposure is now accepted as an occupational disease by the Swedish National Social Insurance Board.[38]

The results of this NIOSH study should be interpreted with some caution. If the neuroperformance decrements measured were the result of solvent exposures, it is puzzling that higher airborne concentrations were not detected in Building 84. It is possible that the exposures measured during the day of the NIOSH visit reflected lower exposures than are typically found in Building 84, or lower than may have existed in the past. It is also possible that there were other differences in the groups completely unrelated to the exposures that the study team was unaware of. For example, the workers from the control group have jobs that require them to be attentive or alert when reading written material, which is not the case for the workers in Building 84. The practice with such tasks could favor the control subjects on tests of attention or alertness. There is a mean difference in the ages of 3.9 years between the exposed and unexposed group. The younger control workers might be expected to perform better than the slightly older exposed workers. Lastly, selection bias may have been introduced by the poor participation rate among a subsegment of the control workers, or workers from shipping and receiving who do well on this type of test may have been the only workers who chose to participate.

VIII. CONCLUSIONS

Although the exposure to volatile organic vapors measured during this investigation were below the limits recommended by NIOSH (except for potential carcinogens), workers from Building 84 scored lower on neurobehavioral performance tests measuring attention and alertness than did the unexposed controls. Although these differences suggest the possibility of effects resulting from long-term low-level solvent exposures prior to the NIOSH on-site investigation, an inadvertent study bias as explained above could also account for these differences.

IX. RECOMMENDATIONS

The NIOSH investigators made the following recommendations after the initial site visit to Building 84 in an interim report submitted to the employee representative and Lockheed-Georgia management representatives on September 16, 1983. To the extent feasible, Lockheed complied with these recommendations prior to the NIOSH follow-up survey.

1. The top of the waste solvent storage pit should be covered as much as possible to prevent solvent vapors from evaporating when the spray booth is not in use.

2. Parts, especially the larger parts, awaiting inspection should be given enough time to dry in the spray booth or placed in an open area where no workers would be exposed.

3. Facial hair should not be allowed for workers assigned to spray clean parts inside the spray booth. Facial hair (even a few days growth) prevents a good seal between the surface of a respirator facepiece and the wearer's skin.

4. Lockheed should study the feasibility of moving workers not directly involved in spraying to an adjacent building where parts could be delivered after drying. Otherwise, the inspector's and structural assembly worker's work benches in Building 84 should be moved as far away from the spray booth as possible.

In follow-up to our previous recommendations (No. 3), a recently published study on the effect of facial hair on the face seal of negative-pressure respirators,[39] found that bearded subjects wearing half-mask respirators had a median fit factor of 12 (8% leakage) vs. a fit factor of 2950 (0.03% leakage) for clean shaven subjects. The average quantitative fit test results showed a 240 fold drop in half-mask respirator protection for bearded subjects when compared to the clean shaven subjects.

After reviewing our final results for this investigation NIOSH also recommends that:

1. Lockheed minimize the use of Turco® T-1000 for the spray cleaning of wing parts because this solvent contains two suspected or potential carcinogens (methylene chloride and tetrachloroethylene) in its formulation.

2. Lockheed should evaluate its use of neoprene rubber rain suits for protecting workers from solvent spray. NIOSH recommends butyl rubber or Viton® elastomer gloves, aprons, or other protective garments for protection against exposure to liquid phase 1,1,1-trichloroethane.[40] Neoprene rubber latex or nitrile rubber latex may be used in cases where the protective garment will not be in contact with either the liquid or saturated vapor of 1,1,1-trichloroethane.

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XI. DISTRIBUTION AND AVAILABILITY

Copies of this report are currently available upon request from NIOSH, Division of Standards Development and Technology Transfer, Publications Dissemination Section, 4676 Columbia Parkway, Cincinnati, Ohio 45226. After ninety (90) days the report will be available through the National Technical Information Service (NTIS), Springfield, Virginia 22161. Information regarding its availability through NTIS can be obtained from the NIOSH Publications Office at the Cincinnati, Ohio address.

Copies of this report have been sent to:

1. Lockheed-Georgia Company
2. Representatives for Employees
3. NIOSH Region IV
4. OSHA Region IV
5. Designated State Agencies of Georgia

For the purpose of informing the approximately 25 "affected employees", the employer will promptly "post" this report for a period of thirty (30) calendar days in a prominent place(s) near where the affected employees work.

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TABLE 1

DEMOGRAPHIC & OTHER CHARACTERISTICS
OF SOLVENT EXPOSED WORKERS AND CONTROLS

HETA 83-369
LOCKHEED-GEORGIA COMPANY
MARIETTA, GEORGIA

(February 1984)

	Exposed (N=7) Number (%)	Not Exposed (N=13) Number (%)
Caucasian	4 (71)	9 (69)
Black	3 (43)	3 (23)
Male	6 (86)	11 (85)
Female	1 (14)	2 (15)
Prior job with chemical exposure	5 (71)	12 (92)
Drinkers (>6 drinks/week)	2 (29)	4 (31)
Drinkers (>1 drink in last 24 hrs.)	2 (22)	1 (8)
Medications affecting nervous system	1 (14)	4 (31)
Smokers	1(14)	6 (46)
Age (mean in years)	46.9	43.3

[illegible]
for SUBSTANCES MEASURED in BUILDING 840
HETA 83-369
LOCKHEED-GEORGIA COMPANY
MARIETTA, GEORGIA
(February 1984)

SUBSTANCE	OSHA PEL**	ACGIH TLV***	NIOSH RECOMMENDATION	HEALTH EFFECTS CONSIDERED	REFERENCE
1'1'1-trichloroethane (methyl chloroform)	350 ppm	350 ppm	350 ppm (ceiling-15 min)	Nervous system, liver, & heart effects	41
Perchloroethylene	100 ppm	50 ppm	LTFL	Nervous system effects; respiratory, eye, & skin irritation; suspect carcinogen	20
Trimethyl benzene	--	25 ppm	--	Mucous membrane irritation, nervous system effects	12
Methylene chloride	500 ppm	100 ppm	75 ppm	Central nervous system effects, carbon monoxide toxicity	14
Xylene	100 ppm	100 ppm	100 ppm	Central nervous system depressant, respiratory irritation	42
n-Butyl alcohol	100 ppm	50 ppm (ceiling-15 min)	--	Eye & mucous membrane irritation, hearing loss & impaired vestibular function	12
Diacetone alcohol	50 ppm	50 ppm	--	Eye, nose, & throat irritation; objectionable odor & taste	12

* Limits are 8-hour time-weighted averages (TWA) unless otherwise stated.
** For OSHA standards, see Reference No. 10
*** For ACGIH TLV's, see Reference No. 11

ppm = parts per million parts of air
LTFL = lowest technically feasible limit

TABLE 3
RESULTS OF AIR MONITORING FOR SOLVENT VAPORS

HETA 83-369
LOCKHEED-GEORGIA COMPANY
MARIETTA, GEORGIA
(February 1984)

Job Classification/ Sampling Location	Sampling Duration	Solvent Vapor Levels Detected During Spraying with Turco T-1000					
		PERC	TMB	MC	Xylene	Butanol	DA
Building 84:	February 7, 1984:						
Solvent sprayer	8:20am-12:37pm	2.8	1.1	5.8	0.2	0.2	0.2
Inspector	8:10am-1:38pm	0.2	ND	0.5	ND	NS	NS
Structural repairman	8:25am-1:30pm	0.3	0.1	ND	ND	NS	NS
Inspector	9:51am-12:16pm	0.5	0.1	NS	ND	0.5	ND
Insp. bench (area)	8:50am-1:00pm	0.4	0.2	ND	ND	ND	ND
Core cutter mechanic	10:08am-1:20pm	0.6	ND	2.2	ND	NS	NS
		Solvent Vapor Levels for Controls					
		PERC	TMB	MC	Xylene	Butanol	DA
Control Subjects:	February 6 & 8, 1984:						
Receiving inspector	9:53am-2:16pm	ND	ND	ND	ND	NS	NS
Traffic office worker	10:20am-2:24pm	ND	ND	NS	ND	NS	NS
Receiving inspector	10:06am-2:18pm	ND	ND	NS	ND	NS	NS
Tool design tech	10:36am-2:40pm	ND	ND	NS	ND	NS	NS
Tool designer	8:16am-12:30pm	ND	ND	ND	0.7	NS	NS
Tool designer	8:57am-12:32pm	ND	ND	NS	ND	NS	NS
Paint stores rec. Insp.	10:24am-1:12pm	ND	ND	ND	ND	NS	NS
Recommended occupational exposure limits (TWA)		50	25	75	100	C 50*	50

All samples represent personal exposures unless otherwise noted
All exposures in parts per million (ppm)

PERC = perchloroethylene
TMB = trimethyl benzene (aromatic petrolium solvent)
MC = methylene chloride
DA = diacetone alcohol

ND = none detected
NS = not sampled
TWA = 8-hour time weighted average
*C = ceiling limit
LTFL = Lowest Technically Feasible Limit (NIOSH recommended limit for known or suspected carcinogens)

TABLE 4

RESULTS OF AIR MONITORING FOR 1,1,1-TRICHLOROETHANE VAPORS

HETA 83-369
LOCKHEED-GEORGIA COMPANY
MARIETTA, GEORGIA
(February 1984)

Job Classification/ Sampling Location	Sampling Duration	Exposures During Use of Solvent 111
Building 84:		
Metal bond repairman	12:14pm-3:03pm	0.7 ppm
Inspector	12:40pm-3:02pm	1.0 ppm
Inspector	12:30pm-2:58pm	1.1 ppm
Solvent sprayer	12:37pm-2:56pm	23.0 ppm
Insp. bench. (area)	1:07pm-2:56pm	1.0 ppm
Structural repairman	1:30pm-3:00pm	0.6 ppm
Inspector	1:38pm-3:01pm	0.5 ppm
Core cutter mechanic	1:21pm-2:44pm	1.6 ppm

All samples represent personal exposures unless otherwise noted

Recommended occupational exposure limit (TWA)	350 ppm

TWA = 8-hour time weighted average
Note - Exposures to trichloroethane were not detected for control subjects

TABLE 5

SYMPTOM AND DISEASE PREVALENCE
SOLVENT EXPOSED WORKERS & CONTROLS

HETA 83-369
LOCKHEED-GEORGIA COMPANY
MARIETTA, GEORGIA

(February 1984)

Symptom or Disease	Exposed (%)	Not Exposed (%)	p value
"Have you ever been seen by a doctor for:"			
Diabetes	0	1 (7.7)	.87
Migraine	1 (14.3)	0	.72
Heart Disease (including arrhythmias)	2 (15.4)	0	.68
Liver Disease	0	2 (15.4)	.68
Kidney Disease	0	1 (7.7)	.81
High Blood Pressure	4 (57.1)	6 (46.2)	.93
Neurologic Disease	0	0	1.00
Asthma	2 (28.6)	1 (7.7)	.58
Upper Respiratory Disease	2 (28.6)	5 (38.5)	.79
"In general, are you troubled by the following:"			
Fatigue	1 (14.3)	0	.75
Vegetative Symptoms	2 (28.6)	4 (30.8)	1.00
Parathesias	2 (18.6)	1 (7.7)	.60
Affect Lability	1 (14.3)	8 (61.5)	.74
Lack of Concentration	2 (28.6)	1 (7.7)	.60
Memory Difficulty	1 (14.3)	8 (61.5)	.21
Gross Neuropathic Symptoms	0	0	1.00
Lack of Sexual Interest	0	2 (15.4)	.74
Sleepiness	2 (28.6)	6 (46.2)	.78
Excited for no Reason	0	0	1.00
Unusual Taste	1 (14.3)	1 (7.7)	.87
"During the past two weeks have you had:"			
Numbness or Weakness	3 (42.9)	2 (15.4)	.59
Symptoms of Narcosis (dizziness, lightheadedness, etc.)	2 (38.6)	1 (7.7)	.58
Symptoms Suggestive of Atherosclerotic Heart Disease	1 (14.3)	2 (15.4)	.86
Insomnia	1 (14.3)	2 (15.4)	.97
Unusual Fatigue	1 (14.3)	0	.75
Symptoms Unrelated to Solvent Exposure (gastrointestinal symptoms and toothache)	0	0	1.00
Respiratory Symptoms	3 (42.9)	6 (46.2)	1.00
Dermatologic Symptoms	3 (42.9)	3 (23.1)	.74

TABLE 6

BEHAVIORAL TEST RESULTS
SOLVENT EXPOSED WORKERS VS. UNEXPOSED WORKERS

HETA 83-369
LOCKHEED-GEORGIA COMPANY
MARIETTA, GEORGIA

(February 1984)

	AVERAGE SCORES		
Simple Reaction Time (release)	UNEXPOSED	EXPOSED	PROBABILITY
Preshift	329 msec	338 msec	0.61
Postshift	376 msec	329 msec	0.40
difference (postshift-preshift)	+47	-9	0.40
Simple reaction time (response)			
Preshift	185 msec	206 msec	0.28
Postshift	193 msec	212 msec	0.13
Difference (postshift-preshift)	+8	+6	0.53
Santa Ana Test			
Preshift	17 pegs	--	--
Postshift	18 pegs	19 pegs	0.57
Difference (postshift-preshift)	+1	--	--
Wechsler Memory Scale			
Preshift	7.8 facts	5.8 facts	0.24
Postshift	9.3 facts	7.4 facts	0.10
Difference (postshift-preshift)	+1.5	+1.6	0.50
Multi-Attention Task			
Preshift	29 dist.	27 dist	0.19
Postshift	29 dist.	24 dist.	0.02
Difference (postshift-preshift)	0	-3	0.07
Bourdon-Wiersma			
Preshift	261 sets	226 sets	0.007
Postshift	274 sets	222 sets	0.001
Difference (postshift-preshift)	+13	-4	0.04

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