K1590 #1418

NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH

COOPERATIVE AGREEMENT

Award No. 1 U01 OH 01249-01

FINAL REPORT

UNIVERSITY OF UTAH

ROCKY MOUNTAIN CENTER FOR OCCUPATIONAL AND ENVIRONMENTAL HEALTH

WILLIAM N. ROM, M.D., M.P.H.
PRINCIPAL INVESTIGATOR

Closing Date December 31, 1982

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Department of Health and Human Services
Centers for Disease Control
National Institute for Occupational Safety and Health

AWARD NUMBER: 1 U01 OH 01249-01
HHE Number: 81-458
Work Assignment No.: 1
Effective Date: November 19, 1981
Recipient: University of Utah (W. Rom)

A. Description of Work

The recipient shall conduct an initial on-site environmental/medical evaluation of potentially exposed workers at the Hill Air Force Base, Ogden, Utah, not later than December 15, 1981. This investigation will be conducted under the authority of Section 20 of the Occupational Safety and Health Act, in the manner specified in 42 CFR 85 and 85(a). Such investigation will be expected to result in information sufficient to develop a protocol for follow-up environmental/medical investigations. Specifically the recipient should:

1. Conduct an initial evaluation consisting of initial conferences with management and worker representatives (usually together), perform a walk-through survey of the work areas in question, and make a review of all pertinent medical/employment/environmental data in possession of the company, schedule possible additional conferences with management, labor and/or medical groups, and conduct a closing conference in which immediate recommendations can be made and likely follow-up studies or reports indicated.

B. Level of Effort

The recipient agrees to devote direct labor effort to the performance of the work assignment approximately as follows:

Professional Classification	Estimated Man Hours
Occupational Health Physician	22
Industrial Hygienist	22
Clerical	50

C. Reporting Requirements

The recipient shall submit all environmental/clinical data developed und this work assignment to the NIOSH Technical Advisor. The final result will be an interim report and a specific proposal (protocol) for further study.

1. Not later than December 23, 1981, the recipient will make a verbal report to the technical advisor briefly indicating the background of the investigation, what actions have been taken to date, what has been found to date, and future actions planned.

At this time, the recipient should indicate whether the investigati should be closed out without further on-site environmental/medical study, or if further environmental/medical studies are felt to be necessary. If further investigation is felt to be appropriate the recipient should also indicate whether or not an interim report should be sent to the employer/employees.

2. If it is determined that no further environmental/medical investigation is needed, the recipient will submit a final report, including interpretation of the available data. The specific form of the report will be according to NIOSH published guidelines (and agreed upon by the NIOSH Technical Advisor). A draft of this repo (five copies) should be provided to the NIOSH Technical Advisor fo review/publication not later than February 15, 1982. Once NIOSH approval of the report is obtained, the Technical Advisor will forward a copy of the report to the NIOSH Grants Management Office

3. If it is determined that further investigations are needed, th recipient should submit a protocol for these studies, to the Grant Management Officer, with copies to the NIOSH Technical Advisor. protocol will include itemized cost estimates for these studies. it is determined that an interim report should be sent to the employer/employee representative, a draft of this report (five copies) should be sent to the NIOSH Technical Advisor, not later February 15, 1982.

4. All final reports required of the recipient will be sent to t Grants Management Officer, NIOSH, with copies sent to the NIOSH Technical Advisor.

D. Release of Funds

1. $1,629 of direct costs (Personnel $1,600, Travel $29) plus the appropriate Indirect Costs are released for performance of this work assignment.

Joseph W. West
Grants Management Officer

Cooperative Agreement Work Assignment

Award Number 1 U01 OH 01249-01

HHE Number 81-458

Work Assignment No.: 1

I. Hill Air Force Base is Utah's largest employer with approximately 12,000 civilians and 6,000 Air Force personnel. Hill Air Force Base was constructed during the early years of World War II near Odgen, Utah. The Directorate of Maintenance is responsible for repair and overhaul of military aircraft and missiles. The local union (American Federation of Government Employees, Local 1592) has charged that their members have been over-exposed to industrial chemicals over the years resulting in excessive morbidity and mortality.

In 1978, worker complaints prompted an initial NIOSH Health Hazard Evaluation. NIOSH made eight recommendations including an analysis of cancer cases, industrial hygiene monitoring, to identify trade names, to conduct occupational health medical surveillance, and to consider prospective or cross-sectional medical studies. In response, the Air Force industrial hygiene program found that the chemicals that they monitored were within permissable exposure levels, that there appeared to be no unusual cancer incidence or occupational association, and that hazard medical examinations were, in general, within normal limits.

Congressional hearings were held by the U.S. House of Representatives in April 1979 and the U.S. Senate in July 1981. A mortality study was deemed feasible by the National Cancer Institute, and has been funded by the U. S. Air Force. The mortality study will determine the vital status and cause-specific mortality of 20,000 civilian employees by the end of 1979, who had been on the payroll anytime in 1952. The Senate hearings resulted in funding by NIOSH of a Health Hazard Evaluation (HHE) by the University of Utah to determine the feasibility of morbidity studies. Funding was provided through a NIOSH Health Hazard Cooperative Agreement with the University of Utah covering medical and industrial hygiene evaluations.

NIOSH Health Hazard Evaluations are conducted under Sections 19 and 20 of the Occupational Safety and Health Act of 1970. The rules have been promulgated under Executive Order 12196 October 1, 1980 and published in the federal register (29 CFR Part 1960 - Basic Program Elements for Federal Employee Occupational Safety and Health Programs; Final Rule, specifically 1960.35 NIOSH).

II. Initial Conferences

An initial conference to review the task of the HHE was held on November 13, 1981 with the U.S. Air Force. Twenty-two officials attended including Richard McKenzie, Deputy Director of Maintenance; Col. Victor C. Furtado, Director of Bioenvironmental Engineering for the U.S. Air Force; Col. E. G. Horne, M.D.; and Harold S. Jensen, M.D., Director of Occupational Medicine Services at Hill Air Force Base. A joint meeting with the union was considered infeasible at that time. Appendix 1 lists meeting attendees.

Discussions at the initial meeting included the following: cooperation, advantage of an objective academic third party, news media, the NIOSH HHE program, and the requirements of Task 1 including a walk-through and assessment of medical/employment/environmental records.

The walk-through was conducted on November 19, 1981, and Dr. W. Rom had a meeting with the Ogden Air Logistics Center Commander, General Marquez, to review the HHE.

On November 20, 1981, faculty of the Rocky Mountain Center for Occupational and Environmental Health (RMCOEH), University of Utah, met with members of the AFGE Union Local 1592 at 4:00 p.m. on their own time. The identical agenda was followed. The Union was requested to identify high hazard areas and buildings.

The U.S. Air Force stated that release forms had to be signed for review of personnel and medical records. The Union was cooperative in obtaining 70 release forms signed for us to sample and determine what type of information was collected and on file.

III. Employment Records

Employment records were reviewed on December 21, 1981, by Ki Moon Bang, Ph.D. (epidemiologist-biostatistician). Files of all current civilian employees are maintained by the Civilian Personnel Office. Those of retired civilian employees or those who separate are sent to the National Personnel Records Center in St. Louis, Missouri. Records of transferred employees are sent to their new military base.

The Official Personnel File included the following information: work history including position title, dates, occupational code, and an administrative assignment; previous job history; training history; job performance (supervisory evaluation); supplemental experience and qualification statement; employee's notice of injury or occupational disease awards; and health insurance.

Computerization of employment data has begun (1981) but is limited containing job grade level, social security number, name and birthdate.

Eleven personnel records were pulled and reviewed. The workers had had from 3 to 11 different jobs with an average of 7. It was feasible to create a chronological occupational history from the records and classify workers into various job categories e.g. aircraft sheet metal mechanic, aircraft electrician, landing gear repairer, electronic equipment worker, instrument sealer, and so forth. It was not possible to identify which building the worker had worked, but specific buildings had various job functions over the years. The employment records were limited (Form 171, completed upon job application) regarding previous jobs prior to beginning work at Hill AFB. They also had limited information on job description and potential exposures. Only two of the 11 employees had filed the form Employee's Notice of Injury or Occupational Disease CA-1; these were both for injuries.

Ex-employees' and retirees' forms would have to be reviewed at St. Louis since they were unavailable at Hill AFB. (These are available upon request from the Air Force, but delivery takes 6-8 weeks.) It would be feasible to determine current job category, how long the employee had worked at Hill AFB, and to develop a chronological work history using available data. However, it would be more difficult to pinpoint the precise location of the employee's work.

IV. Medical Records

Harold Jensen, M.D., Director of Occupational Medicine Services (OMS), provided information on the Hill Air Force Base physical examination program. Pre-employment and other routine physical examinations require CBC, urine analysis, audiology (baseline hearing test), vision test, spirometry, EKG at age 35 and over, and chest x-ray or TB tine test. Examination for work in hazardous areas includes medical history obtained by the examining physician, specified laboratory tests, and physical examination procedures which are determined by the type of hazardous exposure.

The physical and hazard examination program has been in existence for over 30 years with over 3300 done in 1980 and 4200 in 1981. The work places are identified for the hazard program by bioenvironmental engineering when exposures reach a pre-determined action level (one-half the PEL or relevant standard). This is exclusive of hearing tests. The number of workers and work places is constantly being revised as bioenvironmental engineering industrial hygiene evaluations quantify workplace hazards. During 1980 there were 911 hazard exams (including 52 military) and in 1981 there were 1034 (including 91 military).

Appendix 2 lists the recommended tests for exposure to chemicals. These include urine tests for metabolites, complete blood counts, liver function tests, physical examination, EKG, and specific blood tests, e.g., blood lead, carboxyhemoglobin, methemoglobin, etc. Appendix 3 lists how the recommended tests are listed by chemical. Appendix 4 lists several exam protocols listing job or area, exposures, lab tests, frequencies, and applicable organizations.

V. Industrial Hygiene Record Assessment

On December 10, 1981, Jeffrey S. Lee, Ph.D, CIH, and Donald E. Marano, CIH of the RMCOEH Industrial Hygiene faculty met with Lt. Col. M. G. Moody and Mr. T. Sam Vigil (industrial hygienist) of Hill Air Force Base (AFB), Bioenvironmental Engineering Division. The purpose of this meeting was to conduct a preliminary review of available industrial hygiene records at Hill AFB to determine the feasibility of constructing toxic substance exposure histories for workers that may be identified in a morbidity study.

The first part of the meeting focused on the history of the industrial hygiene program both in the Air Force in general, and specifically at Hill AFB. During the period 1944 to 1960, industrial hygiene surveys were conducted at Hill AFB when potential problem areas were identified by either management or maintenance engineers. No annual or routine surveys were conducted during this period and samples were generally analyzed by outside sources such as the Army Air Corps (using Kettering Toxicological Laboratory for air sample analyses), USAF Environmental Health Laboratory personnel from Kelly AFB (Texas), McClellan AFB (California) or Wright-Patterson AFB (Ohio), and outside contractors. In the late 1950s, Hill AFB began to establish its own industrial hygiene program, which continued through the 1960s and 1970s under the leadership of a variety of individuals (many of whom are still alive). Base-line IH surveys were initiated approximately 1966-67. Prior to 1970, complete industrial hygiene records were not routinely kept at Hill AFB, therefore, histories of exposures before that date (if required) will need to be pieced together from information found at other Air Force locations, from the memories of industrial hygiene personnel and workers active during that period and from extrapolation of more recent air sampling results coupled with chemical usage information.

The second part of the meeting concentrated on a review of air sampling records from 1970 to date and of the procedures used by Mr. Vigil to reconstruct exposure histories for workers filing workers' compensation claims. Mr. Vigil obtains a job history from Personnel with details, job title and dates of employment. The job titles do not key into one particular job location, although Mr. Vigil is often able to pinpoint location (and thus quantify past exposure) by relying on his past experience and IH records which may indicate employees exposed. Mr. Vigil has worked at the base since 1951 (and in IH since 1966). Narrative statements are collected from the employee's supervisors describing past exposure conditions and job description. A narrative statement is also requested from the employee. Floor plans of buildings and areas worked are assembled. Finally a report is prepared by Mr. Vigil summarizing available exposure information pertinent to the compensation claim. Although these records have not yet been organized in a manner to provide easy assess for the extraction of exposure information for a specific individual, it appears that the records are adequate to yield such information. These records appear to be more complete than those likely to be found in a typical manufacturing facility for the same period of time. The records are currently maintained by the Bioenvironmental Division (Bldg. 242) and are organized by building (see attached outline of file information, Appendix 5). We have established a good working relationship with members of the Bioenvironmental Engineering Division, therefore, in specific cases where it may become necessary to augment the information found in the exposure records with personal knowledge of past working conditions, we anticipate a cooperative response from appropriate Hill AFB personnel.

Mr. Vigil interviewed several workers who worked that the base in the 1950s, and has assembled them in a file. This material may be worthwhile in attempting to reconstruct exposure histories.

The Bioenvironmental Division currently has an authorized staff of 17. Lt. Col. Moody heads the Division. There are two engineers, two IH's, nine technicians, three computer personnel, and one secretary.

In summary, we believe that the historical worker exposure information available at Hill AFB as well as other locations in the Air Force, coupled with personal knowledge of past industrial hygiene conditions on the base by selected individuals that have worked there for a number of years, permits a reasonable reconstruction of worker exposure profiles. It is believed that these profiles will be more than adequate to provide a classification of degree of exposure necessary for the conduct of a variety of morbidity studies. It is recommended that we principally focus on exposures post-1970 due to available records.

VI. Walk-Through at Hill Air Force Base

On November 19, 1981, the walk-through at Hill AFB was conducted. Present were William Rom, M.D., Jeffrey Lee, Ph.D., Kenneth Casey, M.D., and Ki Moon Bang, Ph.D. Hill AFB personnel accompanying RMCOEH staff were Lt. Col. M. G. Moody, Mr. Jack Olsen, Mr. W. A. Vincent, and Maj. Glenn Gaudet.

Aircraft Division, Directorate of Maintenance

The tour began in building 225 which is the main hangar building, under the Aircraft Division, Directorate of Maintenance. The building is principally devoted to aircraft modification, repair, and maintenance. Mr. R. J. Smith, Deputy Chief, Aircraft Production Branch, provided the tour of this building. He stated that the Aircraft Division has approximately 2400 employees, with 2,050 in production, 200 in material control and scheduling, 80 in planning/engineering and 40 others. He currently has 2,374 civilians and 18 military personnel working three million direct labor hours annually. The attrition rate is approximately 10 percent per year. Personnel tend to begin work at Hill in the Aircraft Division and then transfer to other divisions where higher grades tend to be available;

half of the attrition personnel transfer to other areas on base, while the others go off base. Mr. Smith reviewed the maintenance procedures on the various aircraft that they service, principally F4 and F16 jet fighters. The repair and maintenance schedule is approximately 48 to 54 months, depending on the aircraft model and type.

Table 1

Aircraft Type	No. of Aircraft	Average Repair Time (Days)
F4-D	64	
F4-E	72	124
F4-G	24	
RF-4C	63	
F-16	67	75

Crash damaged aircraft are also repaired in this building. Mr. Smith provided a flow diagram of plane repair and maintenance:

1. Inventory and remove loose equipment (Bldg. 270)
2. Defuel and purge fuel tanks; remove explosive materials (Bldg. 270)
3. Remove engines and strip (if necessary); wash aircraft with a soap solvent (Bldg. 220)
4. X-ray the aircraft for structural damage; x-ray the main spar (Bldg. 216)
5. Remove any equipment in the way of maintenance and/or repair; remove stress plates; remove electronics (Bldg. 225); inspect and document discrepancies (Bldg. 225)
6. Complete work on documented discrepancies; modify aircraft as necessary (Bldg. 225)

7. Reinstall equipment and conduct operational checks; check wiring; install electronics (Bldg. 225)
8. Close-up and clean-up aircraft (Bldg. 225)
9. Check electronics and avionics (Bldg. 233)
10. Paint (paint hanger; Bldg. 220)
11. Check fuel systems (Bldg. 227/228)
12. X-ray again (Bldg. 216); this x-ray is to detect foreign objects in the engine air intakes
13. Check engine condition including fuel controls; check systems on aircraft power (Bldg. 233)
14. Check compass swing (Bldg. 233)
15. Conduct pre-flight check (Bldg. 233)
16. Conduct flight check; work off discrepancies
17. Prepare for delivery
18. Deliver

Mr. Smith stated that employee utilization records (C037E system) are available with origin code down to unit level which can relate occupations to specific locations. Mr. Smith said that 50 percent of his employees work on the day shift; 40 percent on the swing shift; and 10 percent on the graveyard. Every four weeks, the two groups on day and swing shifts rotate. He stated that the major job categories in his group of 2400 people included: mechanics (about 600), electricians (450-500), sheet metal workers (350-400), and painters. X-ray personnel work for the Industrial Products and Landing Gear.

Mr. Smith stated that they currently use 40 to 50 gallons per day of 1,1,1-trichloroethane. They also use dichloroethane.

Building 225

Small daily-use 1-liter squeeze plastic bottles of 1,1,1-trichloroethane are filled at a bulk filling station. Since 1979, the Filling Station area has had a ventilation hood. Mr. Doug Fields was observed filling bottles. Mr. Fields wore a chemical cartridge respirator, however, he also had a beard. He wore rubber gloves, safety glasses, and protective clothing. Employees required to wear respirators are all quantitatively fit-tested. Lt. Col. Moody stated that Mr. Fields was able to pass with his beard. Subsequent review by the Air Force of SGB records indicated this was in error. The ventilation fan was then turned on. He filled the bottles with a spigot. No solvent was noted to spill. Solvent sampling would be appropriate for this area. The Air Force has conducted ventilation measurements showing 90 FPM capture velocity for this hood. Air sampling by the Air Force with Miran 1A has shown that an average concentration of 27 PPM occurs throughout the 17 minute filling operation with short excursions of 200 PPM (TWA 350 PPM).

Building 225 covers approximately 18 acres. No visible dust or significant general odors were present. A large quantity of natural, thermal, and general ventilation occurs through the hangar ceiling.

There are six fuel cells in the fuselage of the F4 aircraft. They first removed the bladder; second, they removed the foreplate; third, a rubber sealant is applied (Mil Spec 8802). Spot cleaning is done using 1,1,1-trichloroethane. The sealant provides a watertight cavity. When the rubber sealant is placed on the base of the fuel cell, the worker is supposed to wear a chemical cartridge respirator and rubber gloves. At the same time, a vacuum local exhaust unit is used to exhaust chemical vapors, which are discharged into the general hangar. The fuselage repair operators that we observed were using the local ventilation device. We did not observe any of the workers wearing respirators; however, none of them were actively applying the solvent or rubber sealant. Safety glasses were observed to rarely be worn (safety glass requirement is based on task). A portion of the structure of the aircraft is made out of a titanium alloy. The titanium is cut and ground as necessary for repair. One of the workers stated that the ventilatory vacuum cleaner is not always available nor used.

Gas and propane fork lifts are used in this building. Sampling for carbon monoxide and organic solvents (passive dosimeters) would be appropriate. (The Air Force has conducted carbon monoxide sampling in Bldg. 225 with results below TWA with forklifts operating.)

Building 233 (Flight Test Building)

This building contains "live" planes. The fuel and ejection seats were observed. The floor of this building is heated. We observed several planes here going through final checks. The building appeared very clean. Strict fire protection procedures are adhered to. Signs specified that hearing protection should be worn in the building. Employees rarely wore protection (RQD by task). We also noticed a vehicle going through the various bays, washing and cleaning the floors.

Building 216

This is a large, isolated x-ray facility. Radiation measurements have been performed by Hill AFB personnel and the USAF Occupational and Environmental Health Lab (Brooks AFB, Texas).

Building 220

A. Small-parts painting

Three workers were observed spray painting small parts using polyurethane paint. Building 220 is a long building. Workers wore coveralls and air-supplied hoods ("White Caps"). They would spray into a paint booth, the back of which had a waterfall and ventilation system to ventilate the paint vapors and solvent vapors away from the worker.

Dr. Rom spoke to one painter who had been employed at that job for nine years. He stated that he did not have any problems with wheezing, chest tightness, or breathing. He stated that he uses a regular respirator for epoxy paints and an air-supplied respirator for polyurethane paints.

B. Mixing room

One person is assigned to the paint mixing room. They rotate people through this area for training purposes. We observed an oven room in this area that was for "wrinkle paints". Isocyanate-based paints were observed. Acetone is predominately used as a solvent. Some odors were present. A hood was supplied for mixing paints. We did not observe anybody working in this room.

C. Paint shop

There was a large hangar-type building where planes are painted with a spray method and a water fall and ventilation system to direct the vapors and paint fumes away from the worker. The workers have complete coveralls and wear air-line respirators during the actual painting process. Cleaning is done with MEK and toluene often in confined areas (airline respirators are required in confined areas). Cleaning rags with these solvents were observed lying about (disposed of after each major task). Organic solvent sampling is indicated.

Dr. Rom spoke to three workers involved in preparing an aircraft for painting. One man had been employed for two years and the second for 13 years and a third for two days. None of them reported ever having any breathing or health problems doing this process. An OSHA inspection, resulting from an employee complaint, was conducted in this area last year (results apparently showed no OSHA violations).

D. Paint cleaning and stripping

A soap and hot water solution is used to clean and strip paint off the aircraft. A soap solvent is used for this process called 20-20-MV (B & B Chemical Co., Miami). Exact chemical composition was unknown (the composition is available at chemical lab). They stripped the leading edges of the aircraft by hand and brush including a solvent mixture called 50-75-MP, which was brushed on and used in the stripping process. We were told that this contains methylene chloride, (about 60 percent) and several other solvent and soap-like materials. A chemical cartridge respirator was worn by the workers as they did this process (air sampling has been conducted by the Air Force indicating concentrations are below TWA). However, at least one employee had long sideburns which may have prevented an effective facepiece seal. They were also supplied with complete coveralls and gloves.

Dr. Rom spoke to one female worker who had been employed for one year. She stated that she did not have any specific health problems but complained that the vapors occasionally were bothersome.

E. Small part paint stripping

There were six people employed in this area per shift. A new slot-booth ventilation system was utilized. Formerly a smaller ventilation system was employed. Exposure measurements for organic solvents would be appropriate. A gas-fired fork lift was observed. They were older employees. Dr. Rom spoke to one of the oldest employees who stated that he had never had any health problems in this area. Very small parts are stripped by hand using solvent (paint stripper). The workers wear chemical cartridge respirators and have an exhaust ventilation booth to direct the solvent vapors away from them.

<u>Buildings 227/228 (Fuel Building)</u>

The Fuel Buildings are used for fueling aircraft. Entrance is restricted to authorized personnel. Fire is the major potential hazard. A static plate is at the door to remove static charge. The building is open all around the floor to direct fuel vapors away from the aircraft and employees. Jet fuel, JP-4, is used for these aircraft.

<u>Hazardous Materials Storage (Bldg. 256)</u>

Large quantities of hazardous materials (e.g., MEK, Methanol, 1,1,1-trichloroethane) are stored here. A chemical usage supply inventory (computerized) has been maintained for approximately the last 10 years. It should be possible to reconstruct some historical usage patterns from this inventory.

Industrial Products and Landing Gear Division, Directorate of Maintenance

This division includes the plastics shop, gun shop and plating (Cd, Ni, Ag) shop. Primary work is with landing gear and Building 507 is called worldwide landing gear overhaul facility. The building is only 2½ years old. Lt. Col. Frank Murphy is Deputy Chief of this Division. They also have 13 employees in a machine shop on the west base ("1900 zone"). Two other facilities are off base, one at Little Mountain, which is a chemical and solid propellant facility; the second facility off base is at Lakeside, which is where they abrasively cut off missile casing. This Division spends 40 percent of its time in the repair and overhaul of landing gear and 60 percent in industrial products (structural repair, canopies, ejection seats, hydraulic components, life rafts, etc). They have considerable metal plating, sheetmetal work, and are responsible for the beryllium room. Forty-eight buildings are in the Division. This Division is the largest bulk user of chemicals on base. Cleaning and stripping chemicals are received in bulk.

A. Building 507 Landing Gear Facility

Landing gear components are manufactured out of steel, magnesium, and aluminum. Steel and magnesium parts are immersed in an alkaline/corrosion remover, including methylene chloride. Specific formulations of stripping and cleaning compounds are changed from time to time based on mission requirements, contract bids, etc. The paint stripping of the aluminum is different but uses methylene chloride. Odors were present (Air Force sampling has shown concentrations below TWA). Abrasive blast facilities are located at several points in the building. These appear to be well controlled and use walnut shells (agasite) for the blasting material. There is a very large area of this building used for acid and other chemical stripping and cleaning. The landing gears are dipped and held in these large tanks for varying periods of time. There are two stripping lines - one for steel parts and one for aluminum. The tank ventilation is push-pull local ventilation and appears excellent. Some of the chemicals utilized include chromic and phosphoric acids, sodium hydroxide, various bisulfates, kerosene and fluoride salts. Our tour guides were unable to explain to us precisely what was in each tank. The tank's labels did not list every chemical constituent in the tank (due to proprietary restrictions). There is also an ultraviolet quality control operation for inspecting the landing gears. The ultraviolet is used to fluoresce a dye bath to detect hairline fractures. A magnetic particle inspection process is also included here. There is a reassembly area where there are coating booths and several paint booths for spraying on polyurethane paint. Spraying is done in spray booths with waterfalls. There is a machine shop where grinding and metalizing of various metals, including chromium and nickel is performed. Only three employees were seen here.

Building 507 contains a foundry which we did not visit due to lack of time. Two employees work in this area. Lead, brass, and bronze castings are made.

B. Building 505 Plating and Stripping Operation

Here we saw further dipping, including nickel and chromium plating and anodizing. There are three shifts in this building, with 60 to 70 employees. Nickel stripping is done with sodium cyanide, sodium hydroxide, and various organics. Chromium stripping is done with sodium hydroxide and electrical current. Aluminum shells are stripped in this area as well. We observed a cadmium room that was very closely controlled. Cadmium is deposited by a vacuum deposition process. Respirators are required in this area. Abrasive blasting was done with glass beads, aluminum hydroxide, aluminum oxide (Al_2O_3), and garnet. Stainless steel, aluminum parts, and carbon steel are blasted.

C. Building 265 Sheet Metal Building

This building contains a small chemical milling operation. Metal parts are chemically reduced to lower weight. Shapes are traced using a paper form onto the part and then the area that is not to be dissolved is blocked out. A sodium hydroxide solution is used to dissolve off part of the aluminum. Toluene and xylene are also used in this process. There are two vapor degreasers in this area that currently use 1,1,1-trichloroethane.

D. Building 251 Plastics Shop

Forms are made for various molds. Polyurethane, plastics, epoxies, and phenolics are used in this area. A large ventilation hood is available for use when working with these materials in the liquid state. Forty-five employees employees work here with 30 on the day shift and 15 on the swing shift. There are nine females. Methyl-ethyl-ketone and xylene solvents are used. A crib, under lock and key, is used for storage of resins and solvents. In the back of this building, F-4 canopies are rebuilt. Plexiglass is purchased already formed from PPG.

E. Building 258

This building contains a flame and plasma spray area. They work with stainless steel, chromium, aluminum, molybdenum, bronze, and nickel, and the various metal spray operations. There is also 1,1,1-trichloroethane degreaser in the area. There is a possibility of vinylidene chloride formation (CH_2CCl_2) here.

F. Building 204 Beryllium Building

The beryllium building appears well controlled. All operations are under local exhaust. Respirators have been required in the area since the start of beryllium operations in 1974. The beryllium is wet blasted and chemically cleaned. No dust is generated in this process. They use some chromic acid, salts, and various fluorides in their dipping operations here. The beryllium is removed from the brake proper. The broken pieces of beryllium not repairable are sold as salvage back to beryllium manufacturers. The beryllium is used for the brakes of a C-5 transport because of its refractory characteristics and light weight. The major problem here seems to be with the handling and deposition of toxic beryllium-contaminated toxic materials other than worker exposure. The workers wear complete coveralls and respirators while working in this area. We were told that beryllium measurements had been regularly obtained but were generally non-detectable or far below the action level.

G. Building 214 (Mr. G. Val Lofgreen was our tour guide for this building)

Building A (Precision Measurement Equipment Laboratory): This is the second floor of this building and a contractor does most of the work here. This is a controlled environment, with a stated contamination level of fewer than 300,000 particles/M^3 less than 0.5 microns in the air. It includes a machine to clean the shoes; the humidity is controlled at 50 percent. This building is used for precision measurements. In the back end of this area, there was a manometer that contained mercury. Two years ago, about 5 cc of mercury spilled (the mercury was reportedly immediately removed by Chem Lab personnel). They now are developing a special area for mercury control.

Navigation Systems: Small navigation instruments are repaired in this area. Trichloro-trifluoroethane (a freon) is used here as an electrical contact cleaner.

Organic Work: Optics for aligment and bore sights are done in this area. There is a beam balance. Calibrator and temperature measurements are done for electronics room.

Building B Bearing Shop: This is an area that has fewer than 100,000 particles/M^3 in the air. Again, 1,1,1-trichloroethane, freon, and methanol are used as solvents. The bearings are cleaned in a Stoddard solvent degreasing tank with local exhaust. There is an air change in this building every three minutes.

Navigation Systems Repair Area: Bench-type work is performed here utilizing small cans of freon-based cleaners. Some soldering work is conducted.

Missile and Parachute Shop: This was a mirror image of Building 100.

H. Building 100

Before 1965, this was a U-shaped building with railroad tracks coming down the center. The bays in this area were modified in 1965. The center part of the U-building is now Bay J. This is a warehouse. There is also an area in Bay J for soldering and an area for polyurethane painting. They paint sidewinder missiles in this area; however, we did not see this because it is currently under construction. They are planning to use robots to do this painting.

Bay A Building 100: This is an air-controlled area to less than 300,000 particles per cubic meter. It is an Optical Instrument Shop. Here, they repair lenses, sextants, and coat lenses. Acetone is a commonly used solvent. Lens distortion testing center is here. There is also a column area for checking the accuracy of navigation devices. Three workers are employed in a specific room that utilizes a ruby laser. This room was not in operation since the three employees were out in the desert testing the laser instrumentation. We observed employees sitting at tables and using solvents in small plastic bottles.

Bay B Instrument Repair Shop: This is a bench-work area where fuel flow indicators are repaired. Solvents are used out of small plastic bottles. 1,1,1-trichloroethane is used in this area.

Bay C Equipment Testing Room: Work currently done in Bldg. 214 was formerly conducted in here. They test equipment here for the F-16. Freon 113, isopropyl alcohol, acetone and any nitrogen are used here. A microminiature repair area is part of this bay. Xylene and naphtha and isopropyl were used here. An odor was present.

Bay D Astrotracker Repair Shop: Here freon is used, as well as Windex, 1,1,1-trichloroethane and acetone. A spray booth was in this area and had a double lock. There was some soldering done under a hood using a tin copper seal for the astrotracker in this area. The solder is 63 percent lead and 37 percent tin. In this area, we noticed a sign change that had gone to trichloroethane from trichloroethylene. 1,1,1-trichloroethane is used for degreasing. Chloroform was used until 1978 and trichloroethylene until 1968. Freon 113 is used in this area.

Bay E Physical Sciences and Chemistry Lab: Forty scientists are employed here in analytical control. They do water analysis, nuclear magnetic resonance analyses, gas chromotography, mass spectrometry, and also have a scanning electron microscope with an electron microprobe for testing various samples.

Records: We met with Civilian Personnel Office (CPO) personnel to review the available records. CPO told us that we would have to have the person's permission to review their records. We also reviewed the medical record of Richard McKenzie, as an example of a medical record. This was a typical military medical record. They explained that they had a hazard program begun prior to 1960. There are 4200 workers in this physical and hazard program who have a physical examination every one to three years. There are over 40 hazard categories.

VII. Close-out Meeting

On February 2, 1982, we had a close-out meeting with representatives of Hill AFB and AFGE Local 1592. The draft report of Task 1 was reviewed with both parties, and Hill AFB personnel provided input to the Walk-Through summary.

An outline and approach to Task 2 was discussed and a proposed outline is enclosed. Task 3 which is a pilot study was briefly discussed.

VIII. Access to Personal Information (memo 1 February)

The University of Utah agrees to safeguard and not to disclose any personal information during the feasibility morbidity study, and as a sub-contractor to Westat on the mortality study. A copy of the memo forms Appendix 6.

Appendix 1

Name	Organization	Duty Phone
Jack Olson	X12	75961
Paul B. Garrett	XP	75623
Reed Murdock	JA	74886
E. G. Horne, Jr.	SG	75457
S. Copperman	JA	76961
R. McKenzie	MA	63815
Col Victor C. Furtado	HQ AFMSC/SGP	AV 240-2452 COM 536-2452
Maj Robert A. Capell	AFLC/SGB	AV 787-6210
Col Robert A. Owens	OOALC/SE	777-2931
William A. Vincent	OOALC/XR	777-5611
Leon Whipple	XRXP	75961
Connie Smith	Public Affairs	75201
John Russell	MA	777-2813
Kenneth L. Patchin	History Office	777-4005
George Tracy	DS/DSME	74295
Nancy Valenski	DPCEB	76142
Fran Salazar	DPCEB	76142
Sue Huckleberry	DPCEB	77205
T. Sam Vigil	SGB	74525/74551
Lt Col M. G. Moody	Hospital/SGB	74551
Capt R. A. Skier	SGB	74543
Dr. Harold S. Jenson	SGC	73030
William N. Rom, M.D.	University of Utah	581-8719
James E. Lockey, M.D.	University of Utah	581-3455
Jeffrey S. Lee, Ph.D.	University of Utah	581-7107
Ki Moon Bang, Ph.D.	University of Utah	581-5830

Appendix 2

Recommended Tests For Exposure to Chemicals

Pulmonary:

1. Pulmonary function studies, FVC, FEV
2. Chest X-ray - PA - Baseline
3. Chest X-ray - PA - Baseline & Annual

Urine:

1. Urinalysis - Albumin, sugar
2. Urinalysis - Complete including microscopic
3. Urine mercury
4. Urine trichloroacetic acid
5. Urine - hippuric acid
6. Urine acetone
7. Urine 2,5 dichlorophenol
8. Urine thiocyanate
9. Urine UDMH
10. Urine phenol
11. Urine arsenic
12. Urine strychnine

Blood:

1. Hct
2. Hct, Hgb, WBC
3. CBC with indices
4. Blood lead
5. Blood cholinesterase
6. Blood G-6-P dehydrogenase (baseline)
7. Blood carboxyhemoglobin
8. Blood chloroform
9. Blood methemoglobin
10. Blood gammaglustamyl Transpeptidase
11. SGOT, SGPT, Alk Phos
12. SGOT, SGPT, Alk Phos, Bilirubin

Cardiovascular:

1. Pulse, BP
2. EKG, Baseline
3. EKG, Baseline & Annual
4. EKG, Baseline & Annual after age 40

Eyes:

1. Superficial exam
2. Visual acuity
3. Superficial & fundoscopic exam

Other:

1. Complete physical exam
2. teeth exam
3. Pelvic x-rays
4. Complete neurological exam
5. peripheral neurological exam
6. Skin exam

Appendix 3

Chemicals	Pulm	Renal	Blood	Cardio	Eye	Other
	Tests					
Acetates (methyl, ethyl, n propyl, isopropyl, m-Butyl Amyl)	1	1			1	6
Alcohols						
Amyl Alcohol	1					6
n-Butyl alcohol	1				1	6
methyl alcohol		1			2,3	6
Aluminum	1				1	6
Ammonia	1,2				1,2	6
Antimony	1	1	2	2		
Arsenic (inorganic)	1,3	11	2		3	1,6*
Asbestos	1,3					
Beryllium	3,1	1		11		1*
Benzene		10		3		1*
Biphridyls (diquat) (paraquat)	1				3	6
Cadmium	1,3	2,4	3			
Carbonates (baygon, carbaryl (sevin) thiram, vapam, zectran)			5			
Carbon monoxide			7			
Carbon Tetrachloride		1	2,11			1,4
Chlorinated benzenes	1	1	11			6
Chlorinated Hydrocarbons (kepone, heptachlor, lindane, erdine, DOT, mirex, thiodan, toxaphene, aldrin, chlordane, dildrin, benzene hexachloride)		1	11			1,4
Chlorobromomethane	1		1,7			6

Chemicals	Pulm	Renal	Blood	Cardio	Eye	Other
Chlorodiphenyls (PCB)	1		11			6
Chloroform		1	11		1	6
Chromium hexavalent	1,3	1	2,11			1
Chromic acid	1,3	1	2,11			1

Etc.

Appendix 4

EXAM 10

Welders

Exposed to:

Fluorides	Manganese	Al	Ozone
Zinc	Chromium	Oxides of Nitrogen	
Nickel	Cadmium	Pb	
Fe	Copper	Titanium	

Lab tests:

Pulm	Renal	Blood	Cardio	Eye	Other
1,3	2,4 9,11	2,3,4	1	1	2,4,6

Frequency: Initial
Annual
Termination

Organization Applicable to:

(1) Welding Shop, Bldg. 274, MADIS
(2) Welding Shop, Bldg. 30, DEMBM
(3) Welding Shop, Bldg. 507, MANPWW
(4) Welding Shop, BLDG. 800, DSFF
(5) Equipment Maintenance, Bldg. 849, DSFF
(6) Some Workers, Heavy Crating Section, Bldg. 849, DSTEE
(7) Some Workers, Tractor and Trailer Overhaul, Bldg. 847, MAKPE
(8) 399 CRS Welding Shop, Bldg. 39, 388 CRS/MACB

Appendix 5

A. WORKPLACE AND EMPLOYEE DATA

1. Building Number (And/OR Name):

2. Organizational Symbol/Shop:

3. Supervisor:

4. Phone Number:

5. Location:

6. Floor Plan:

7. AFSC:

8. Number of Personnel Assigned:

9. Light Surveys:

10. AF Form 332:

B. OPERATIONAL DATA

1. Description of Operations Conducted:

a. Air Directives

b. Technical Orders (TOs)

c. Other Directives

2. Functional Account Codes (FAC), "Organizational Structural Code", Functional Address Symbol" may be used instead of FAC:

3. Description of Potential Health Threats and List of Hazardous Materials Used:

a. Potential Health Threats

b. List of Hazardous Materials Used: See attached list

4. Available Personal Protective Equipment and Use Strategies. See attached list.

5. Description of In-Use Engineering Controls:

6. Description of Routine Work Practices and Controls:

7. Ventilation Surveys

B. OPERATIONAL DATA (CON'T)

8. Chemical Listings

C. INDUSTRIAL HYGIENE AND ENVIRONMENTAL QUALITY:

1. Applicable Monitoring and Surveillance Requirements:

2. Schedule of Monitoring:

3. Equipment Requirements

4. Air Sampling

5. Dosimetry (Mercury, Noise, etc)

D. POLLUTION CONTROL

1. Description of Engineering Controls:

2. Description of Process Controls and Waste Disposal Procedures:

3. Issue Exception Code (IEX):

4. Material Safety Date Sheets (MSDS):

5. Radiation:

6. Unhealthy Conditions

   a. AF Forms 3

   b. AFLC Forms 916

Cooperative Agreement Work Assignment
Follow-up Survey
Department of Health and Human Services
Centers for Disease Control
National Institute for Occupational Safety and Health

AWARD NUMBER: 1 U01 OH 01249-01

HHE NUMBER: 81-043

WORK ASSIGNMENT NO.: 2

EFFECTIVE DATE: November 19, 1981

RECIPIENT: University of Utah (W. Rom)

A. 1. Description of Work:

The recipient shall assist in the conduct of a follow-up on-site environmental medical evaluation of potentially exposed workers at Koldaire, Inc., Salt Lake City, Utah, not later than January 1, 1982. This investigation will be conducted under the authority of Section 20 of the Occupational Safety and Health Act, in the manner specified in 42 CFR 85 and 85(a). Such investigation shall be expected to result in information sufficient to generate a further final report to the workers/employer and/or informaton sufficient to develop a protocol for further follow-up environmental/medical investigations, if necessary. Specifically, the recipient shall:

a. Administer an occupational and medical questionnaire.

b. Perform nerve conduction velocities using surface electrodes.

c. Perform general physical examinations.

d. Perform laboratory tests: CBC with differential, urinanalysis, ZPP, SMA-20.

Sections a-d will be done on a population consisting of approximately 22 current refrigeration workers, 7 ex-workers, and 15 control workers.

e. For current workers only, perform post-shift resting EKG's, sprometry, and chest X-ray.

f. For selected study participants with abnormal exams suggesting muscle atrophy or with abnormal nerve conductions, perform electromyography utilizing monopolar needle electrodes.

2. Before doing work under paragraph 1 and/or 2 above, should assure that each examinee is provided with a complete study definition utilizing the NIOSH Human Subjects Research Participation Document (HSRPD). Inform each examinee of his/her right to discontinue participation in the study without prejudice, measures to be taken to protect his/her identity relative to information from questionnaires or test results, his/her rights under the Privacy Act, and the possibility that his/her medical records may be required for purposes of the project.

3. Provide immediate notification by the examining physician to the examinee of any significant abnormalities which require immediate medical attention and suggest follow-up health care by his/her personal physician or the plant physician as appropriate. A written report of such findings will be submitted to the NIOSH Technical Advisor immediately. Notify each examinee by letter of the findings of the examination performed on him/her as soon as possible after the examination. Provide NIOSH Grants Management Officer with copies of notification letters.

B. Level of Effort:

The recipient agrees to devote direct labor effort to the performance of the work assignment approximately as follows:

Professional Name Classification	Estimated Man Hours
Senior Occupational Physician	40
Neurologist	76
Occupational Medicine Resident	353
Statistician	28
Physicians Assistant	106
Clerk	52
Administrator	8

C. Reporting Requirements:

The recipient shall submit all environmental/clinical data developed under this work assignment to the NIOSH Technical Advisor. A written report of the follow-up survey in the format of the final report must be furnished to NIOSH by March 1, 1982. This report could take the form of a terminal report or otherwise suggest a protocol for further follow-up surveys.

1. Not later than January 7, 1982, the recipient will make a verbal report to the Technical Advisor briefly indicating the background of the investigation, what actions have been taken to date, what has been found to date, and future actions planned.

2. Should further investigations be recommended, the recipient shall submit a protocol for these studies (including itemized cost estimates) to the NIOSH Technical Advisor and Grants Management Officer. If it is determined that a written interim report is required, a draft of this report (five copies) shall be sent to the NIOSH Technical Advisor not later than March 1, 1982.

3. If it is determined that no further environmental/medical investigation is needed, the recipient shall submit a final report which includes an interpretation of the available data. The specific format of the report shall follow guidelines published by NIOSH as agreed upon by the NIOSH Technical Advisor. A draft of this report (five copies) shall be provided to the NIOSH Technical Advisor for review/publication not later than March 1, 1982. Contingent upon NIOSH approval of the report, the recipient shall forward a copy of the final report to the NIOSH Grants Management Officer and to the Technical Advisor.

D. Release of Funds:

$20,549 of direct costs (personnel $10,900, laboratory $9,649) plus the appropriate indirect costs are released for the performance of this work assignment.

Joseph W. West
Grants Management Officer

Health Study of Refrigeration Workers

HE 81-043

I. Initial Visit

An initial visit was made to Koldaire, Inc., of Salt Lake City, Utah, on January 20, 1981. In attendance were one of the owners of Koldaire, Inc., three of the employees, three physicians from the University of Utah and a NIOSH industrial hygienist. The health problems relating to refrigeration work as perceived by the workers were discussed. Later, an industrial hygiene survey and walk-through were conducted.

II. Introduction

This HHE was the result of a request by a former Koldaire, Inc., employee who became ill while working in the refrigeration trade. He developed a progressive neurologic illness in 1978 which he attributes to exposures he encountered as a refrigeration serviceman. He was hospitalized at the University of Utah Medical Center in August 1978 by a neurologist who wanted to learn more about his illness. His diagnosis was distal axonopathy consistent with toxic chemical exposure. The neurologist caring for this worker invited ten co-workers to the University Medical Center for similar evaluations in October 1978. Many showed evidence of decreased sensory nerve conduction velocity, an early sign of distal axonopathy. A review of the literature showed no association between this illness and refrigeration work. A more in-depth study was proposed to further elucidate any relationship between refrigeration work and neurologic disease.

Refrigeration workers perform two major tasks, construction and servicing. Construction of refrigeration systems involves soldering and welding of copper tubing. This is done prior to introducing the refrigerant into the system. Once the system is constructed it is charged with a refrigerant gas. Usually one or more of the following are used: dichlorodifluoromethane (fluorocarbon 12, FC 12), monochlorodifluoromethane (fluorocarbon 22, FC 22) and chloropentafluoroethane (fluorocarbon 115, FC 115).

Servicing is the other major task and it involves checking the system for leaks and repairing them. Leaks are repaired using solder and a heat source. As fluorocarbons pass through the leak and into the heat source, thermal decomposition produces phosgene, hydrogen chloride, and hydrogen fluoride gases. Cadmium may be present in the solder and represents another potential exposure.

Since repairing leaks is done as needed, a serviceman may be called in at any time of the day or night, and this can result in a long and exhausting work schedule. A refrigeration worker may perform primarily service or construction or both during any given time period. Their exposures will vary depending on the time spent at each task.

I. Health Hazard Evaluation

A. Study Design and Analytical Methods

The purpose of the medical aspect of this HHE is to assess the acute and chronic health effects common to refrigeration workers. This study focused on the organ systems known to be affected by fluorocarbons and their decomposition products, i.e., the cardiopulmonary system, and on the alleged toxicity to the nervous system, especially the peripheral nervous system. Medical examinations and testing were done on Saturdays thereby minimizing the detection of possible acute effects.

Subjects were selected from Koldaire, Inc., and included all personnel involved in servicing. This excluded several young employees who worked only in the warehouse area and who were not regularly exposed to welding fumes or fluorocarbons. In addition, the eight workers studied previously were invited to attend. All but one, the index case, who left refrigeration work on the advice of his personal physician, were still in the refrigeration trade. This resulted in a group of 30 workers, 28 of whom participated in the medical tests.

Tests included a complete medical history and physical examination performed by an occupational physician. Nerve conduction studies were performed by a neurologist and included a bilateral assessment of the following nerves: ulnar motor and sensory, median motor and sensory, peroneal, tibial, and sural. A standardized occupational history and symptom questionnaire was administered by one of two trained interviewers. Respiratory function was assessed with the forced vital capacity maneuver. A 12-lead ECG and chest radiograph were also used to assess cardiopulmonary status. Blood was obtained for a complete blood count, routine chemistries, and a zinc protoporphyrin level to assess prior lead exposure. A routine urinalysis was done. Information regarding respiratory symptoms was obtained through a self-administered, modified BMRC questionnaire. A second self-administered questionnaire gathered information on alcohol consumption.

A comparison group of fifteen workers employed as plumbers, pipefitters and insulation workers is presently being studied. The group is being selected from rosters of local unions. Potential participants are screened over the telephone by a physician to exclude those with previous neurologic disease or previous exposure to fluorocarbons. The same studies are being performed except chest radiographs, pulmonary function tests, and electrocardiograms.

The results will be analyzed in three ways. First, the prevalence of various abnormalities will be presented for the group as a whole. The index case will be presented separately, however, for comparison purposes. The second way will be a comparison between those working more than the median number of years and those working less than the median number of years to give a high and low exposure comparison. The final analysis will be a follow-up of the eight previously studied workers.

B. Toxic Substance Medical Data

The toxicity of fluorocarbons has been under investigation since the 1930s. The narcotic properties are well recognized and occur at concentrations in the 10-20 percent range. They were considered extremely safe at much lower dosages and found their way into many products as aerosol propellants. In the 1960s sudden deaths occurred in asthmatics using hand-held inhalers containing fluorocarbons. In addition, deaths from inhalation of other aerosol products containing fluorocarbons gave rise to renewed interest in fluorocarbon toxicology (1).

Aviado devised a classification scheme for propellants based on their acute cardiopulmonary effects (2). FC 12 and FC 22 are Class III propellants indicating intermediate toxicity. They result in early respiratory depression and bronchoconstriction which predominates the influence on circulation. FC 12 produces depression of minute volume, bronchoconstriction, and reduction in compliance in most animal species tested at concentrations near 10 percent. FC 22 produces the same findings at concentrations of 20 percent. FC 115 is a Class IV propellant with lower cardiopulmonary toxicity than Class III. Concentrations of 20 percent or more are required to produce the same effects as Class III propellants.

Cardiac effects for Class III and Class IV propellants include arrhythmias, tachycardia, myocardial depression and hypotension. Sensitization of the canine myocardium to preinjected epinephrine results in arrhythmias at concentrations of 5 percent for FC 12 and FC 22 and, at concentrations of 20 percent, FC 115 (3).

In an extensive human volunteer study, Stewart et al. studied the effects of FC 12 on the cardiopulmonary and nervous systems (4). Eight males underwent a four week exposure to 1000 ppm FC 12, eight hours per day, five days per week. No untoward health effects occurred either at the termination of the experiment or at a one year follow-up.

Speizer et al. reported that a significant number of pathology personnel experienced palpitations after use of FC 12 or FC 22 (5). Twenty-eight percent of pathology personnel reported palpitations while only 14 percent of radiology personnel experienced this symptom. Measured levels of FC 22 were near 300 ppm.

Neurobehavioral changes after acute inhalation of FC 12 have been reported in man and in animals (6,7). Van Stee and McConnell observed elevation of liver enzymes in animals after FC 22 exposure (8). They recommended monitoring SGOT and SGPT of exposed workers. There have been no reports of any fluorocarbon producing peripheral nervous system disease. The current TLV for all three fluorocarbons is 1000 ppm (9).

Phosgene gas is a well-known respiratory irritant producing acute pulmonary edema which may lead to emphysema. The present TLV is 0.1 ppm (9). Hydrogen chloride produces upper respiratory symptoms of sore throat, cough, and choking. The TLV is 5 ppm (9). Hydrogen fluoride causes upper respiratory irritation as well as pulmonary edema. The current TLV is 3 ppm (9). Cadmium fume inhalation can cause pulmonary edema. Chronic cadmium intoxication can produce proteinuria, renal damage and possibly emphysema. Prostatic carcinoma has also been associated with cadmium exposure. The ceiling value for cadmium is 0.05 mg/m^3 of the fume and 0.2 mg/m^3 of dust (9).

C. Results and Discussion

1. Index Case

The index case is a 33-year-old white male who began refrigeration work in 1971 with Koldaire, Inc., working mainly in construction. In 1976, he began doing primarily servicing work. It was at this time that he states his health began to gradually decline with loss of weight, difficulty concentrating, depression, and weakness in the arms and legs. In the summer of 1978, he received a large exposure to fluorocarbons when a pipe that he was repairing broke open. Within hours he became ill and had to leave work. His symptoms included nausea, vomiting, abdominal pain and weakness. He remained off work for three weeks seeing several doctors for this illness. He was evaluated at the University of Utah Medical Center in late July by a neurologist who found abnormalities in his nerve conduction velocities. The following values were obtained: left peroneal nerve was 40 m/sec (at the lower limit of normal), left tibial nerve was 22.6 m/sec (lower limit of normal is 35 m/sec), and left sural nerve was 20.8 m/sec (lower limit of normal is 37.5 m/sec). Following these findings he was hospitalized to discover the cause for his illness. No cause was found and he was discharged with the diagnosis of "axonal polyneuropathy, possibly on the basis of intoxication or metabolic defect."

He then returned to refrigeration work with a different company working as a construction supervisor. He left after eleven months. Since then he has worked as a truck driver and a pipefitter. He is currently unemployed. Convinced that his refrigeration work was responsible for his illness, he has filed a workman's compensation claim which was denied. He is presently pursuing an appeal of this decision.

This worker was examined at the University of Utah Medical Center on December 19, 1981, along with other members of the study group. At that time he appeared chronically ill and thin. His general physical examination was otherwise unremarkable. The neurologic examination revealed normal strength, coordination, reflexes and gait. Sensory examination revealed a peripheral stocking-glove polyneuropathy. Laboratory examination was entirely normal. Nerve conduction studies had markedly improved giving the following results for the three previously reported nerves: left peroneal nerve was 46.5 m/sec, left tibial nerve was 45.6 m/sec, and left sural nerve was 34.9 m/sec. Other nerve conduction studies were consistent with the group as a whole.

Responses to the symptom questionnaire were significantly different than the group as a whole. He reported 27 symptoms of a possible 34 from the standardized questionnaire. The mean number of responses for the remaining 27 was 5.6 (SD = 3.8). Of the 27 symptoms, 23 had definite associations to work. Among the causes he listed were work in general (8), fluorocarbons (7), phosgene (4), welding (2) and mixed exposures (2).

2. Study Group

a. Physical Examinations

This group comprised 27 white males between the ages of 19 and 55 with a mean age of 32 years. Mean duration of full-time employment in the refrigeration trade was 9 years ranging from a half year to 30 years. No cases of distal axonopathy were detected by physical examination. Ten had evidence of mild hypertension as defined by a systolic blood pressure greater than or equal to 140 mmHg but less than 160 mmHg and/or a diastolic blood pressure greater than or equal to 90 mmHg but less than 105 mmHg. Eight were found to have abnormalities in sensation in the arms or legs. These could be related to minor trauma in four, an acute back strain with sciatica in one, surgical repair of a fractured tibia-fibula in one, heavy callous formation of the hands in one, and previous spinal surgery for a hemangioma in another. These findings potentially confounded the nerve conduction studies. This was overcome by using the right- or left-sided nerve, whichever had the greatest nerve conduction velocity, or by excluding the person from the statistical analysis if both sides were involved. The worker with sciatica had bilateral involvement and therefore the nerves in his lower extremities were excluded from the analysis. The worker with previous spinal surgery was excluded entirely.

b. Symptoms

Symptoms are listed in Table 1 with their corresponding frequencies. Each worker was asked if the symptom started or became worse while working in the refrigeration trade. If the response was positive, the respondent was then asked with which jobs or activities the symptom was associated. This number is found in the last column. The index case was excluded from this tally. For comparison his positive responses are included on this table.

Lightheadedness or dizziness was the most common symptom, reported by two thirds of the respondents. Exposure to freons was given as the cause, while phosgene, welding, and servicing were reported once each. Tiring easily occurred in 44 percent. Four workers attributed this to their work including painting (1), exposure to freon (1), exposure to cadmium (1), and long working hours (1). Four others associated it with work, but no particular activity.

Difficulty breathing was reported by 33 percent. This symptom was attributed to welding or soldering near freons (4), to phosgene exposure (1), to exaccerbation of preexisting asthma by freons (1), and to cadmium (1). Headaches occurred in another 33 percent. Workers attributed their headaches to freons (2), phosgene (1), a combination of freon and phosgene (1), and checking leaks in systems (1). Pressure in the chest was also reported by a third of the respondents. Five indicated that this started or was made worse by work. Three others identified either phosgene (2), or soldering near freon (1) as the cause.

Twenty-six percent of respondents had numbness or tingling in their fingers lasting more than a day. Four said this started or was made worse during their refrigeration work. Two others reported phosgene (1) or freon (1) as the cause. Increased irritableness was reported by 26 percent. Two indicated that this started or was made worse with their job while one specifically felt that painting was the cause. Trouble remembering was reported by 26 percent, but most did not know or forgot what this was associated with.

Burning eyes was a symptom reported by 22 percent. Four indicated specific exposures, namely welding (3) and use of a torch (1). Another 22 percent had palpitations. One associated this symptom with freon exposure. Perspiring occurred in another 22 percent. Only one felt that freon was the cause.

Eighteen percent claimed their fingers turned white from cold or vibration. Two reported freon burns from direct dermal contact with liquid refrigerant. Nausea was reported by 15 percent of workers. Two indicated that phosgene was associated with this symptom. Loss of muscle strength occurred in eleven percent. One worker reported a combination of freon and phosgene was the cause, while kneeling was responsible for this symptom in another.

Incoordination was present in another 11 percent. A combination of freon and phosgene was reported as the cause in one case. Seven percent reported losing the feeling in their fingers from cold or vibration. One said this was caused by a freon burn which also turned his fingers white. Another worker reported that handling cold pipes resulted in numbness.

In all, freons were reported as a cause for symptoms 29 times. A variety of symptoms were produced including dizziness (13), shortness of breath (especially during welding or soldering) (5), headaches (3), palpitations (1), perspiration (1), pressure in the chest (1), incoordination (1), tiring easily (1), and causing fingers to turn white and/or become numb as a result of dermal contact (3). Phosgene was implicated 11 times, in association with headaches (2), pressure in the chest (2), nausea (2), difficulty breathing (1), dizziness (1), numbness in fingers (1), and incoordination (1). Soldering or welding were mentioned 9 times. These activities were associated with the following symptoms: burning of eyes (4), difficulty breathing (3), pressure in chest (1), and dizziness (1). Cadmium was mentioned as a cause of symptoms only twice, i.e., difficulty breathing (1), and tiring easily (1).

As expected many respondents reported symptoms referrable to the cardiorespiratory system in accordance with the known welding toxicity of freons and their thermal decomposition products and fumes. Bronchoconstriction may account for trouble breathing and tightness in the chest. Subsequent hypoxia and hyperventilation could explain the dizziness, headaches, tingling in the fingers, tachycardia (palpitations), perspiration, and nausea. Lightheadedness or dizziness was, however, more strongly associated with simple freon exposure. This may result from the CNS depressant effects of fluorocarbons or from hypotensive effects as observed in laboratory animals.

Numbness or tingling in the fingers could be a result of toxic axonopathy, however, this is not consistent with the physical examination findings. Alternatively, direct repetitive trauma to the hands could result in these symptoms. This repetitive trauma was supported by the physical findings of calloused hands, and multiple healed lacerations occurring about the hands. Carpal tunnel syndrome is another common neurologic problem encountered in workers who use their hands extensively which could account for these symptoms. However, there were no cases of this found on physical examination.

Fatigue, irritableness, and headaches are nonspecific symptoms that could result from long working hours and/or physically strenuous work. Burning of the eyes was reported by several workers and was strongly associated with welding and soldering. Few neurobehavioral symptoms were reported and few symptoms of chronic toxicity were reported, e.g., loss of appetite, loss of weight, and increased somnolence.

c. Respiratory Symptoms

There are 8 smokers, 8 ex-smokers, and 12 nonsmokers. Five subjects reported cough or phlegm for three months or more. Hemoptysis was reported by one while breathlessness Grade I was a symptom in three. Nine have wheezing with colds, but only four had wheezing apart from colds. Symptoms of chronic bronchitis were reported by two nonsmokers and one ex-smoker.

d. Blood and Urine

Blood and urine studies revealed few abnormalities. Only one test, SGPT, was abnormal in more than three workers. As seen in Table 2 all but one were mildly elevated. There were four drinkers, one nondrinker, and one ex-drinker in this group suggesting that these elevations were not merely a result of recent alcohol consumption. In the study group, 20 subjects reported they drank alcohol while four reported they were nondrinkers and four reported they were ex-drinkers. As seen in Table 3, there was a trend for drinkers to have a higher SGPT. Table 4 shows the effect of employment on SGPT. Table 5 shows the interaction of the two factors, drinking status and length of employment, on the level of SGPT. These effects are small and not statistically significant, but they do indicate a trend of increasing values with drinking and duration of employment. A comparison population may be of benefit in further analyzing this result.

e. Pulmonary Function

No abnormalities were noted in the pulmonary function studies. Forced vital capacity, forced expiratory volume in one second, and the ratio of these two were normal in all subjects. There was little difference between smokers and nonsmokers, with smokers tending to have somewhat lower values for all three parameters.

f. Chest Radiographs

Several minor nonwork related abnormalities were noted and will not be mentioned specifically. One case of a diffuse bilateral miliary nodular pattern was evident in a 43-year-old worker who had no history of pneumoconiosis or other lung disease. A repeat chest x-ray was unchanged one month later. This worker refused further diagnostic testing. He was asymptomatic and had normal pulmonary function tests. His physical examination revealed no evidence of respiratory pathology. Since this patient had worked and traveled in areas where coccidioidomycosis is endemic, it is believed that the chest x-ray represents an old, benign, granulomatous disease of fungal origin. He was advised to have repeat chest x-rays on an annual basis to follow any progress in this condition.

g. Electrocardiograms

There were 10 abnormal tests, four had sinus bradycardias, four had nonspecific ST-T changes, two had first degree A-V block, one had evidence of a previously undiagnosed inferior myocardial infarction and only one tracing had a single premature ventricular contraction.

h. Nerve Conduction Velocities

These are shown in Table 6 for the entire group with the index case listed separately for comparison. These are not corrected for skin temperature. The average velocity for the group on the sural nerve conduction is low. Since this is a purely sensory nerve and lies close to the skin, its velocity is affected by skin temperature, decreasing the rate 2 m/sec per degree centigrade below 30°C. In Table 7 nerve conduction velocities are broken down by length of employment. No consistent differences are seen here even though one might expect to see somewhat slower velocities among the group with longer length of employment on the basis of a higher mean age. Further analysis of nerve conduction velocities, distal latencies, and sensory action potentials is forthcoming.

The follow-up study results are shown in Table 8. Some of the nerves were not tested. Most changes occurred toward increasing nerve conductions while a few decreased. All changes were mild and probably within the limits of error of nerve conduction technique. No change in materials over this time period could account for the improvement in nerve conduction velocities.

D. Conclusions

There are several limitations in the design of this study. First, the study population is a survivor population in that all were still employed in the refrigeration trade except the index case. This produces a bias toward negative results. Second, the size of the study group is small. Small effects are therefore more difficult to detect. This was not a problem with the nerve conduction velocities between the high and low exposure groups as no meaningful differences were detected but may be a problem when comparing results to the control group. It was a problem in relation to the elevations of the SGPT levels which showed small, but not statistically significant differences between the two groups. Third, nerve conduction velocities can vary depending on the equipment used, the expertise of the operator and the inherent variability in repeated measurements on the same individual. This problem was minimized in that only one neurologist performed the examinations using the same equipment. Inherent variability of the measurement may have contributed to the rise in nerve conduction velocities seen in many of the subjects in the follow-up study. Fourth, there are many possible confounding variables associated with nerve conduction velocities. These include trauma to nerves; presence of metabolic diseases, e.g., diabetes, alcoholism, uremia, porphyria, etc...; environmental factors, e.g., skin temperature; exposure to other known and/or unknown neurotoxins at home or at work; use of neurotoxic medications, e.g., isoniazid; nutritional deficiencies; recent viral infection or influenza vaccine; and presence of other known or unknown neurologic disease. Complete medical histories and physical examinations, as well as blood chemistries were used to minimize the influence of these potential confounding variables.

On the other hand, the participation rate of 93 percent was high and enhanced the validity of the study. In addition, the use of a control group will help minimize the effects of the small study group size and lend more credence to the findings from the symptom questionnaire.

In summary, peripheral nerve disease does not appear to be related to exposures encountered in the refrigeration trade. However, analysis of sensory action potentials, a sensitive indicator of early axonopathy, is still in progress as well as the evaluation of the control group data. Therefore, definitive conclusions regarding nerve injury can not yet be made. The possibility of peripheral neuropathy in the index case on an allergic or hypersusceptible basis due to exposures encountered in refrigeration work cannot be excluded with absolute certainty, however, this would be an unlikely mechanism as all known neurotoxins produce peripheral neuropathy in a dose-related manner.

A tentative positive finding was elevations in SGPT. The effect, if any appears to be small and is confounded by the effect of alcohol consumption. The possible exposure to high concentrations of fluorocarbons supported by the high frequency of reporting of dizziness may represent a potential hazard. The Occupational Health Guideline for FC 12 indicates exposures of 50,000 ppm cause dizziness in humans and 150,000 ppm cause unconsciousness (10). Therefore, some acute exposures causing dizziness in these workers may well be in excess of 50,000 ppm. It is unlikely that they reach 150,000 ppm as no cases of loss of consciousness were reported. Fatal arrhythmias occur in animals presensitized to epinephrine at 500,000 ppm FC 12 or FC 22. However, it has not been determined what levels will produce this effect in humans. Presumably, the threshold concentration would be lower in workers with preexisting arrhythmias. Even if the threshold concentration for the production of arrhythmias in predisposed workers were half the value found in animals, there would still be a fourfold or fivefold margin of safety at 50,000 ppm.

Another consideration at these high levels of fluorocarbon exposure is the proportional increase in phosgene gas production during soldering or welding. No instances of acute pulmonary edema were reported, but the potential long-term consequences of overexposure to phosgene should be considered.

IV. Recommendations

The use of respirators during repair of leaks and during other activities which result in high fluorocarbon exposure seem prudent. Elimination of solder containing cadmium when possible or the use of respirators during the use of cadmium-containing solders is recommended.

Medical surveillance should include yearly physical examinations with determination of liver enzymes, specifically SGPT, SGOT, and GGTP, pulmonary function testing and resting electrocardiograms.

Eye protection should be worn during welding and soldering. Gloves should be worn when handling cold pipes or when exposure to liquid fluorocarbons is a possibility.

The opportunity to use ventilation is small because of the on-site location of the majority of the work which is done in this trade.

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VI. Authorship and Acknowledgments

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Table 1

Symptoms Reported by Refrigeration Workers

Symptom	Frequency[a] N	Frequency[a] %	Number Reporting Specific Cause
[b]Lightheadedness or dizziness	18	67	15
[b]Easily tired	12	44	4
[b]Breathing trouble	9	33	7
[b]Headaches	9	33	5
[b]Pressure in chest	9	33	3
[b]Numbness or tingling in fingers	7	26	2
[b]Irritability	7	26	1
[b]Trouble remembering	7	26	0
Burning eyes	6	22	4
[b]Palpitations	6	22	2
[b]Perspiration	6	22	1
Fingers turn white from cold	5	18	2
[b]Difficulty moving fingers	5	18	0
[b]Nausea	4	15	2
Pains in hands mainly at night	4	15	0
[b]Numbness or tingling in toes	4	15	0
[b]Increased effect from alcohol	4	15	0
Nose bleeds	4	15	0
[b]Loss of strength	3	11	2
[b]Abdominal pain	3	11	1
[b]Incoordination	3	11	1
[b]Depression	3	11	0

Table 1 (con't)

Numbness from cold or vibration	2	7	2
[b]Change in gait	2	7	0
[b]Problems buttoning clothes	2	7	0
Sore throat	2	7	0
[b]Lose of 10 pounds or more	1	4	0
[b]Increased sleep	1	4	0
[b]Difficulty driving	1	4	0
Fainting	1	4	0
[b]Lose of appetite	0	-	-
[b]Difficulty concentrating	0	-	-
[b]Difficulty with meaning of words	0	-	-
[b]Confused or disoriented	0	-	-

[a]Excludes index case

[b]Symptoms reported by index case

Table 2

Workers with Abnormal SGPT Level[a]

ID #	SGPT (IU/L)	Age (years)	Employment (years)	Alcohol Consumption
14	105	43	21.0	drinker
10	62	43	6.5	drinker
27	54	39	13.0	drinker
01	53	30	8.5	ex-drinker
18	51	29	6.5	nondrinker
17	47	28	9.5	drinker
Mean		35.3	10.8	

[a]SGPT normal range = 0-45 IU/L

Table 3

SGPT Level by Drinking Status

Drinking Status	N	SGPT (IU/L)	SD
Drinkers	20	32.7	22.0
Ex-drinkers	4	30.2	16.0
Nondrinkers	4	28.0	15.5

Table 4

SGPT Level by Length of Employment

Length of Employment (years)	N	Mean SGPT (IU/L)	SD
> 8	14	35.3	24.5
≤ 8	14	28.1	14.0

Table 5

SGPT Level by Length of Employment and Drinking Status

Drinking Status	Length of Employment (years)	N	Mean SGPT (IU/L)	SD
Drinkers	> 8	11	36.4	26.5
	≤ 8	9	28.2	14.9
Nondrinkers and ex-drinkers	> 8	3	31.3	18.9
	≤ 8	5	27.8	13.8

Table 6

Maximal Nerve Conduction Velocities in Meters Per Second

Nerve	Mean Velocity	SD	Index Case Velocity	Lower Limit of Normal
Ulnar motor[a]	60.0	4.6	64.2	48.0
Ulnar sensory[a]	41.8	4.6	39.4	37.0
Median motor[a]	60.4	4.4	59.2	48.0
Median sensory[a]	42.6	4.4	44.8	37.0
Peroneal[a,b]	49.7	3.2	46.5	40.0
Tibial[a,b]	48.0	6.4	45.6	35.0
Sural[a,b,c]	36.8	4.0	34.9	37.5

[a]Subject with spinal injury excluded

[b]Subject with acute back strain and sciatica excluded

[c]One subject refused test

Table 7

Maximal Nerve Conduction Velocities by Length of Employment
(meters/second)

	Length of Employment			
Nerve	> 8 Years	SD	≤ 8 Years	SD
Ulnar motor[a]	60.0	3.9	59.9	5.4
Ulnar sensory[a]	42.4	4.5	41.1	4.7
Median motor[a]	60.5	4.5	60.4	4.4
Median sensory[a]	42.1	4.5	43.1	4.4
Peroneal[a,b]	49.1	3.3	50.3	3.2
Tibial[a,b]	49.4	6.1	46.6	6.6
Sural[a,b,c]	37.0	3.6	36.5	4.5

[a]Subject with spinal injury excluded

[b]Subject with acute back strain and sciatica excluded

[c]One subject refused test

Table 8

Follow-up Study Maximal Nerve Conduction Velocities
(meters/second)

	Left Ulnar Sensory		Left Median Sensory		Left Sural	
ID #	1978	1981	1978	1981	1978	1981
01	38.0	--	41.0	--	38.0	41.7
04	37.0	37.2	36.0	34.2	30.6	30.6
06	39.0	43.3	43.0	--	34.0	35.7
16	--	--	37.0	41.9	34.8	--
18	--	--	39.0	41.9	37.5	32.6
19	39.0	44.8	39.0	41.9	38.0	40.5
20	38.0	45.4	34.0	44.1	37.5	35.7
26	--	--	30.9	35.4	37.5	35.7

Addendum to HE 81-043

RESULTS

Fourteen nonrefrigeration workers were selected from local union rosters of plumbers and insulators. Individuals were matched by age to the refrigeration workers with the longest employment and who were free of obvious neurologic disease. Prospective subjects for the comparison group were contacted by phone and interviewed by a physician to exclude previous neurologic disease and previous work in the refrigeration trade. A total of 32 individuals were contacted. Seven were not interested in participating, six had pre-existing neurologic disease, and three had worked in the refrigeration trade for more than a year. Of the sixteen scheduled for examinations, fourteen came. Of these, half were plumbers. The fourteen refrigeration workers used for this analysis had an average employment in the trade of 11.4 years (range 5-30 years).

Table 1 shows mean age and mean number of responses on the symptom questionnaire for both groups. The refrigeration group reported 40 percent more symptoms on average, but this was not statistically significant.

As seen in Table 2 there were two symptoms reported significantly more often by refrigeration workers than by the comparison group. These symptoms, lightheadedness or dizziness and palpitations, are the symptoms expected to be associated with fluorocarbon over exposure based on their known toxicity. Of the ten refrigeration workers reporting lightheadedness or dizziness, all ten associated this symptom with fluorocarbon exposure. The five reporting palpitations were unable to associate this with a particular exposure at work, but two stated that their symptoms had started or become worse while working in the refrigeration trade.

In Table 3, SGPT levels are shown for the two groups. A small but statistically insignificant difference exists. Among both groups there were identical numbers of persons who drank alcohol (10), those who were nondrinkers (2) and ex-drinkers (2).

Results of the electromyography are reported in Tables 4 and 5. No statistically significant differences in maximal conduction velocity were noted. The sensory action potentials were estimated to be either less than 20 microvolts or greater than or equal to 20 microvolts. The results were not statistically significant.

CONCLUSION

No evidence exists in this study to support the hypothesis that fluorocarbons or refrigeration work are hazardous to the health of workers. Occasional high exposures to fluorocarbons may be responsible for the excessive number of workers reporting symptoms of lightheadedness and palpitations. Medical surveillance and industrial hygiene controls should be employed as described in the original report.

Table 1

Refrigeration Workers Versus Comparison Workers

	Refrigeration Workers (n=14)	Comparison Workers (n=1[illegible])
Mean Age	34.4	34.6
Range	24-55	25-55
Mean Number of symptoms	5.8	4.1
Range	0-17	0-11
SD	4.5	3.4

e 2

Symptoms Reported by Refrigeration Workers and a Comparison Group

Symptom	Frequency Reported by Refrigeration Workers (n=14)		Frequency Reported by Comparison Workers (n=14)	
	N	%	N	%
Lightheadedness or dizziness*	10	71	3	21
Pressure in chest	6	43	2	14
Headaches	5	36	7	50
Palpitations*	5	36	0	0
Breathing trouble	4	28	4	28
Numbness or tingling in fingers	4	28	1	7
Irritability	4	28	1	7
Burning eyes	3	21		
Perspiration	3	21	4	28
Nausea	3	21	1	7
Abdominal pain	3	21	2	14
Fingers turn white from cold	3	21	1	7
Incoordination	3	21	0	0
Trouble remembering	3	21	2	14
Easily tired	3	21	3	21
Increased effect from alcohol	3	21	1	7
Numbness from cold or vibration	2	14	3	21
Depression	2	14	3	21
Difficulty moving fingers	2	14	1	7
Numbness or tingling in toes	2	14	1	7
Pains in hands mainly at night	2	14	1	7
Loss of strength	2	14	0	0
Nose bleeds	1	7	2	14
Fainting	1	7	2	14
Problem buttoning clothes	1	7	0	0
Change in gait	0	0	2	14
Increased sleep	0	0	2	14

Table 2 (con't)

Difficulty driving	0	0	1	7
Difficulty with meaning of words	0	0	1	7
Sore throat	0	0	0	0
Loss of appetite	0	0	0	0
Loss of 10 pounds or more	0	0	0	0
Difficulty concentrating	0	0	0	0
Confused or disoriented	0	0	0	0

*$p \leq 0.05$ by Fisher's exact test, two-tailed, $\alpha = 0.05$.

Table 3

SGPT Levels*
(IU/L)

	Mean	SD
Refrigeration Workers (n=14)	30.8	14.6
Comparison Workers (n=14)	26.2	15.6

*Difference between the two means is not statistically significant by student t test, two-tailed, $\alpha = 0.05$ (pooled SD).

Table 4

Maximal Nerve Conduction Velocities*
(meters per second)

	Refrigeration Workers (n=14)		Comparison Workers (n=14)	
Nerve	Mean	SD	Mean	SD
Ulnar motor	59.8	4.0	60.2	4.1
Ulnar sensory	43.2	3.6	41.1	5.2
Median motor	60.6	4.8	59.5	3.6
Median sensory	42.8	3.8	41.6	4.2
Peroneal	49.0	3.2	46.9	3.7
Sural	36.8	3.9	37.4	4.0
Tibial	48.6	6.3	48.5	5.3

*Differences between means were not statistically significant by student *t* test, two-tailed, $\alpha = 0.05$.

Table 5

Sensory Action Potentials*

	< 20μV	≥ 20μV
Ulnar Nerve		
Cases	9	5
Controls	12	2
Median Nerve		
Cases	3	11
Controls	1	13
Sural Nerve		
Cases	0	13
Controls	2	12

*no statistically significant differences were detected using Fisher's exact test, $\alpha = 0.05$, two-tailed.

Cooperative Agreement Work Assignment
Follow-up Survey
Department of Health and Human Services
Centers for Disease Control
National Institute for Occupational Safety and Health

AWARD NUMBER: 1 U01 OH 01249-01

HHE NUMBER: 81-458

WORK ASSIGNMENT NO.: 3

EFFECTIVE DATE: May 3, 1982

RECIPIENT: University of Utah (W. Rom)

A. Description of Work:

The recipient shall assist in the conduct of a follow-up on-site environmental medical evaluation of potentially exposed workers at Hill Air Force Base, Ogden, Utah, not later than August 1, 1982. This investigation will be conducted under the authority of Section 20 of the Occupational Safety and Health Act, in the manner specified in 42 CFR 85 and 85(a). Such investigation shall be expected to result in information sufficient to generate a further final report to the workers/employer and/or informaton sufficient to develop a protocol for further follow-up environmental/medical investigations, if necessary. Specifically, the recipient shall:

1. Develop an inventory of major chemicals used at the Base from 1970 to present. For each major chemical, estimate approximate amount used and number of persons exposed by year. Grade each chemical for toxicity from low to medium to high for specific organ systems.

2. From a 20% random sample of current civilian employees, identify study groups with commonality of exposures. Develop an exposure index for each (potential, intermittent, high). Determine the current employees who are in these groups and their length of employment at Hill Air Force Base. Tabulate by age, sex, race, marital status, address, phone number, job status, and current and previous HAFB jobs.

   Examples of study groups include (a) 1,1,1-trichloroethane (and past trichloroethylene); (b) mixed low-level solvents (toluene, xylene, freon, acetone, methyl ethyl ketone, isopropyl alcohol); (c) painters and paint strippers; (d) JP_4 and methyl ethyl ketone (aircraft mechanics); (e) beryllium; (f) nitroglycerin; and (g) unexposed controls.

3. After the NIOSH technical advisor has approved the study groups, conduct a critical literature review on the toxicology and human health effects of the chemicals listed in 2. and approved by the NIOSH technical advisor.

4. From a 20% random sample of current civilian employees, develop an employee file of unexposed workers that may serve as cotrols. Tabulate by age, sex, race, marital status, address, phone number, job status, and current and previous HAFB jobs.

5. From a 20% random sample, determine the ex-employees and retirees for 1979-1981 for the various study groups including controls. Tabulate by age, sex, race, marital status, address, phone number, job status, and current and previous HAFB jobs. Determine for a random sample how many can be located within Utah.

6. Review and evaluate possible morbidity test procedures for a medical evaluation of these exposure groups. After receiving approval of this list from the NIOSH project officer, determine sample size and and B error with biostatistical consultant.

7. Before doing work under paragraph 1 and/or 2 above, should assure that each examinee is provided with a complete study definition utilizing the NIOSH Human Subjects Research Participation Document (HSRPD). Inform each examinee of his/her right to discontinue participation in the study without prejudice, measures to be taken to protect his/her identity relative to information from questionnaires or test results, his/her rights under the Privacy Act, and the possibility that his/her medical records may be required for purposes of the project. The university should also comply with the provisions of the Privacy Act and the provisions of AFR 12-35 relating to the safeguarding of personal data and nondisclosure to third parties.

8. Provide immediate notification by the examining physician to the examinee of any significant abnormalities which require immediate medical attention and suggest follow-up health care by his/her personal physician or the plant physician as appropriate. A written report of such findings will be submitted to the NIOSH Technical Advisor immediately. Notify each examinee by letter of the findings of the examination performed on him/her as soon as possible after the examination. Provide NIOSH Grants Management Officer with copies of notification letters.

B. Level of Effort:

The recipient agrees to devote direct labor effort to the performance of the work assignment approximately as follows:

Professional Name Classification	Estimated Man Hours
Occupational Physicians	261
Industrial Hygienist	348
Epidemiologist	870
Data analyst	435
Clerical support	348

C. Reporting Requirements:

The recipient shall submit all environmental/clinical data developed under this work assignment to the NIOSH Technical Advisor. A written report of the follow-up survey in the format of the final report must be furnished to NIOSH by August 30, 1982. This report could take the form of a terminal report or otherwise suggest a protocol for further follow-up surveys.

1. Not later than August 30, 1982, the recipient will make a verbal report to the Technical Advisor briefly indicating the background of the investigation, what actions have been taken to date, what has been found to date, and future actions planned.

2. Should further investigations be recommended, the recipient shall submit a protocol for these studies (including itemized cost estimates(to the NIOSH Technical Advisor and Grants Management Officer. If it is determined that a written interim report is required, a draft of this report (five copies) shall be sent to the NIOSH Technical Advisor not later than August 30, 1982.

3. If it is determined that no further environmental/medical investigation is needed, the recipient shall submit a final report which includes an interpretation of the available data. The specific format of the report shall follow guidelines published by NIOSH as agreed upon by the NIOSH Technical Advisor. A draft of this report (five copies) shall be provided to the NIOSH Technical Advisor for review/publication not later than August 30, 1982. Contingent upon NIOSH approval of the report, the recipient shall forward a copy of the final report to the NIOSH Grants Management Officer and to the Technical Advisor.

D. Release of Funds:

1. $42,886 of direct costs (Personnel $37,386, Travel $3,971 and Contractual or Third Party Costs $351) plus appropriate indirect costs is released for performance of this work assignment. We understand that some of these funds will be rebudgeted.

Joseph W. West
Grants Management Officer

REPORT ON THE FEASIBILITY OF MORBIDITY HEALTH RESEARCH AT HILL AIR FORCE BASE, UTAH

By the Rocky Mountain Center for Occupational and Environmental Health

Departments of Internal, and Family and Community Medicine

University of Utah School of Medicine

Salt Lake City, Utah 84112

William N. Rom, M.D., M.P.H., Director

NIOSH Health Hazard Evaluation Cooperative Agreement 1 U01 OH 01249-01

January 1983

Running Head: Morbidity Feasibility Report

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Appendices

I. INTRODUCTION

Hill Air Force Base (Hill AFB) is Utah's largest employer with a workforce of over 20,000 employees, including over 13,000 civilians. It is one of 5 United States Air Force (USAF) bases responsible for repair, maintenance, and overhaul of military aircraft and components. There are several operations on base that require the use of a wide variety of chemicals.

The local union (American Federation of Government Employees, Local 1592) (AFGE) has charged that over 1,200 of their members have been overexposed to chemicals, which has resulted in excessive morbidity and mortality. The Air Force maintains that exposures have been kept within recommended and required standards, that controls and protective equipment have been state-of-the-art throughout the years, and that routine and especially targeted health examinations have failed to reveal any excessive occupational-related illness.

The National Cancer Institute (NCI) began a retrospective mortality study in January 1982, to determine if excessive cause-specific deaths have occurred at Hill AFB. The study cohort is composed of approximately 15,000 persons who had worked at Hill AFB for over one year during the period 1952-1956. Exposures of cohort members will be quantified using available data.

The National Institute for Occupational Safety and Health (NIOSH) provided funds under a Cooperative Agreement with the Rocky Mountain Center for Occupational and Environmental Health (RMCOEH) at the University of Utah School of Medicine to collect information necessary to determine whether morbidity studies were feasible at Hill AFB and, if so, to provide the necessary information to develop a study protocol.

Six specific tasks were addressed in this feasibility study:

1) An inventory of major chemicals used at Hill AFB for the period 1970 to present was developed.

2) A random sample of 20 percent of current civilian employees was selected and classified into study groups with commonality of exposures along with pertinent demographic data.

3) A 20 percent random sample of ex-employees and retirees from the 1979-1981 period was selected and classified into study groups along with pertinent demographic data.

4) Using the 20 percent random sample of current civilian employees, the availability of suitable unexposed controls was evaluated.

5) A literature review was conducted on potential study chemicals.

6) Morbidity test procedures were evaluated for potential study groups and sample size, and alpha and beta errors were estimated.

No employees were examined as part of the feasibility study, and, thus, human subject research requirements and notification of findings were not applicable.

The Hill AFB Feasibility Study has a primary focus on evaluating the human health effects from exposure to organic solvents under typical work conditions. The organic solvent chemicals are a disparate group but have a common feature in their narcotic effect. The nervous system may be very sensitive to effects of environmental agents with limited reparative mechanisms. Both neurotoxic and psychological effects from workplace exposures have been identified by

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NIOSH as 2 of the top 10 priority research areas in occupational health for the United States in the 1980s.

In addition to the nervous system, the clinical toxicology of organic solvents is important: exposure kinetics, uptake, distribution, biotransformation, storage, and excretion. Animal experiments suggest that teratogenesis, carcinogenesis, and mutagenesis might occur with some of these compounds. Other organs may be adversely affected by solvents, including the heart, liver, kidney, eye, skin, and lung. This report addresses the feasibility of conducting clinical and epidemiological research on the human health effects of organic solvents at Hill AFB, Utah.

I. MAJOR CHEMICALS USED AT HILL AIR FORCE BASE

Complete historical lists of chemicals used at Hill AFB have not been retained by the Air Force and are not available. Thus, identification of major chemicals, their estimated quantities used, and number of people exposed by year were obtained from the following sources of information:

a) Recent chemical inventories and computer lists available from the Director of Maintenance (13 October 1981, 18 February 1982, and 20 May 1982).

b) Data from a pilot mortality study that was jointly conducted by the USAF and AFGE union detailing specific chemical usage and number of persons exposed.

c) Information obtained from industrial hygiene records dating back to approximately 1970, maintained by the Base Bioenvironmental Engineer for Industrial Hygiene Surveys.

d) Qualitative estimates of exposures and chemical usage based on various walk-through industrial hygiene visits of current operations.

Table I presents the major chemicals used at Hill AFB since 1970. Based T1
on available knowledge, usage of these chemicals could be assumed reasonably constant over this period, with the exceptions of 1,1,1-trichloroethane, trichloroethylene, chloroform, and possibly ortho-dichlorobenzene. Trichloroethylene is not currently used at Hill AFB. During the period 1970-1978, trichloroethylene was used for vapor degreasing instead of the currently used 1,1,1-trichloroethane. Vapor degreasing accounts for approximately 70 percent

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of the current 1,1,1-trichloroethane use or approximately 6,000 gallons/month; thus, for the period 1970-1978, trichloroethylene use could be estimated at approximately 6,000 gallons per month. 1,1,1-trichloroethane was used simultaneously at approximately 2,100 gallons per month during this period. Chloroform is currently used only in one location and in very small amounts (less than 5 gallons/month); however, prior to 1978 usage was somewhat higher, estimated at 20 gallons/month. There is some evidence indicating that ortho-dichlorobenzene was used as a paint stripper prior to methylene chloride, probably as late as the mid 1970s, although not enough data are available to make usage estimates.

From these data we conclude that the major chemicals used at Hill AFB have been chemical solvents. The largest potential exposure has been to 1,1,1-trichloroethane, and previously to trichloroethylene. Methylene chloride has been extensively used as a paint stripper. There is also considerable potential exposure to mixed solvents, viz. methyl ethyl ketone, 1,1,2-trichloro-1,2,2-trifluoroethane (Freon 113), and other unspecified solvents and thinners (e.g., toluene, xylene, acetone, and various alcohols) at levels below 8-hour time-weighted average (Threshold Limit Values (TLVs)).

The TLVs for the potential study compounds were reviewed for the last 15-year period from 1967 to present (1982). Table 2 presents these TLVs T2 along with current Occupational Safety and Health Administration (OSHA) Permissable Exposure Limits (PELs), which were derived from 1968 TLVs or from American National Standards Institute (ANSI) consensus standards in effect in 1970-1972. TLVs were the standards to which exposures were controlled.

In some cases they have been reduced over the years as new information became available indicating effects at lower concentrations.

TLV documentations were briefly reviewed for 1,1,1-trichloroethane and trichloroethylene. The original TLV documentation for 1,1,1-trichloroethane references 4 separate studies, concluding that no significant effects exist below 500 ppm. One of these studies found "subjective responses" (i.e., a "sleepy feeling") in human subjects exposed to 500 ppm for 7 hours per day for 5 days. The TLV of 350 ppm was apparently based on unpublished personal communication to the TLV Committee of "complaints due to odor and mild irritation use and concern over the possible effects of prolonged undue exposure to chlorinated hydrocarbons." The TLV has remained unchanged until the present (1982).

The trichloroethylene standard was 100 ppm in 1967 and remained at that level until 1982 when it was dropped to 50 ppm. It is interesting to note that the Russian standard was 1 ppm (as a maximum allowable, or ceiling concentration) in 1967. Russian standards are typically much lower than TLVs and are based on first detectable effect, such as subtle changes in conditioned reflexes and neurophysiologic changes. The 100 ppm TLV documentation concludes that "there appears to be ample évidence from experience in this country that exposure to trichloroethylene at concentrations below 100 ppm will not cause liver damage or serious central nervous system effects." The documentation cited Swedish and United States studies showing effects below 100 ppm but apparently dismissed them at the time as being "non-serious", concluding that the 100 ppm TLV would protect "most" workers. In 1982, a TLV of 50 ppm was adopted. The updated documentation reviews the available carcinogenesis studies reported since the first documentation, including the National Cancer Institute (NCI) study showing excessive hepatocellular carcinomas in mice intubated with trichloroethylene daily for 18 months. No carcinomas developed in rats similarly exposed. The documentation for the 1982 TLV included a study reporting fatigue, lassitude, and headache in volunteers exposed to 100 ppm and concluded that the new 50 ppm recommended standard would control "subjective complaints" such as headaches, fatigue, and irritability.

. TWENTY PERCENT RANDOM SAMPLE OF CURRENT EMPLOYEES, EX-EMPLOYEES, AND RETIREES BY EXPOSED/NONEXPOSED AND DEMOGRAPHIC VARIABLES

A 20 percent random sample of current civilian employees was selected in May 1982 using the Hill AFB IBM 4700 computer. There were 2,905 in the sample of 14,523 civilian employees. The 20 percent random sample was subdivided into two groups: WG (1,396, 48 percent) as potentially exposed (referred to as exposed) and GS (1,509, 52 percent) as probably unexposed (referred to as controls). The WG is generally blue-collar employment and GS, white-collar employment. It should be noted that there is an overlap between these groups, e.g., up to 30 percent of the exposed may actually be unexposed, and approximately 10 percent of the unexposed are exposed to solvents. However, job categories and industrial hygiene reviews are able to classify these persons. These two groups were chosen solely for the purposes of the Feasibility Study because of the ease of computer access, and to compare demographic variables.

Table 3 lists the frequencies in exposed and control groups by age, sex, race, length of employment, and income level. The age distributions are very similar. There are more females in the white-collar control group, reflecting many working in a secretarial or similar work capacity. Over 90 percent of both groups are white Caucasian. The employment duration is similar, with over 40 percent having more than 10 years' duration of employment. The income levels are different, reflecting over one-third in the white-collar group having higher paying management jobs. Appendix 1 lists the 190 job titles

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of the exposed group and enumerates the number of workers in each job title. One can use the job title list in addition to industrial hygiene data to develop exposure groups of interest for study.

The marital status of the employees (25 percent single, 75 percent married) was obtained at the time of employment and may not be current. The addresses and phone numbers for the 20 percent random sample could not be obtained from the Personnel Office because of protections afforded by the Federal Privacy Act.

From the 20 percent sample, Table 4 categorizes potential study groups T4
with commonality of exposure. Table 5 lists the number of workers in each T5
commonality of exposure category by level of exposure. By definition, exposures less than one-half of current TLVs were considered "low" while exposures in excess of one-half of current TLVs were considered "high". The 20 percent random sample of employees was separated into 9 potential study groups based on commonality of exposure. This categorization was based on information obtained from walk-through investigations, limited review of industrial hygiene files containing industrial hygiene surveys, and consultation with Hill AFB bioenvironmental personnel. All workers in the 20 percent sample were classified as exposed or unexposed, and classified further by exposure level and category. There were approximately 300 workers exposed to high continuous or intermittent levels of solvents. Also, exposure categories F-I have few employees (beryllium, nitroglycerin, jet fuel, and welders). The total of 981 differs from the 1,396 as potentially exposed, reflecting the fact that there are some blue-collar workers who

probably are not exposed to organic solvents. Also, there were 33 GS employees in the list, reflecting the few (about 10 percent) of white-collar employees who might be exposed.

A 20 percent random sample was also selected for ex-employees and retirees terminating between 1979 and 1981. There were 709 selected from a potential 3,545 persons. For each person, demographic variables tabulated included age, race, employment duration, and income level (Table 6). The sample was again T6 divided into CS/WC employees as potentially exposed and probably unexposed. However, addresses and phone numbers could not be obtained because of protections provided by the Privacy Act. Age, race, and employment duration were similar, but there appeared to be a high turnover in the lower-paying white-collar office jobs. Table 7 lists the total number of exposed ex-employees T7 and retirees in the various commonality of exposure groups by exposure level. Another 39 potential study subjects were exposed to high continuous or intermittent levels of solvents. Of note is the fact that the percentage of employees resigning in the high-exposure categories (23/59, 59 percent) was much higher than the percentage of employees resigning in the low-exposure categories (19/89, 21 percent).

A 10 percent random sample of the 709 ex-employees and retirees was obtained to determine how many could be located within Utah during January 1983. We were able to locate 91 percent (64/70) still within Utah using current telephone directories and police information (Table 8). Almost two-thirds T8 had remained in the Ogden area.

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A further potential study cohort is long-term employees identified from the mortality study being performed by the National Cancer Institute at Hill AFB. The mortality cohort is defined by 1 years' employment between 1/1/ 52 and 12/31/ 56. About 15,000 persons are in this cohort of which 6,600 are an exposed male cohort. Vital status will be determined through 12/31/ 80. The study is primarily concerned with cancer mortality, especially neoplasms of the lymphatic and hematopoietic systems because of known or suspected relationships with solvent exposure. Approximately 1,200 older employees of this cohort may still be employed at Hill AFB, and a subgroup may have been exposed to organic solvents in the 1950s and 1960s. As part of the NCI mortality study, employment histories and lifetime exposures will be obtained. These workers may be available for study for the chronic effects of organic solvents, although this represents a "survivor" group. Those who may have suffered ill-effects possibly from solvents may have left employment long ago.

Controls whó are unexposed are best selected from the white-collar (GS series) workers or unexposed blue-collar workers (WG series). Almost 65 percent of the random sample are potential controls (approximately 1,475 from the GS series and 450 from the WG series). Similar results were obtained for ex-employees and retirees.

Four major occupational groups are available for possible research. First are employees with degreaser activities who have 1,1,1-trichloroethane exposure since 1978 and trichloroethylene pre-1978. Second are employees primarily in Building 100 reassembling aircraft instruments. They are exposed to mixed solvents that vary from Bay to Bay. The mixtures include toluene, xylene, Freon 113, acetone, methyl ethyl ketone, 1,1,1-trichloroethane, and various alcohols. Each worker uses from 2 to 4 solvents concurrently. Each Bay (or area; there are about 8) has a computerized listing of all chemicals and amounts used monthly, which is continuously updated. The third group is aircraft mechanics who (primarily) use 1,1,1-trichloroethane and methyl ethyl ketone, with occasional exposure to small amounts of jet fuel while working in confined spaces. Fourth is the paint strippers, who use a paint-stripping mixture that is approximately 70 percent methylene chloride and 30 percent others, including phenols. Spray painters are a fifth potential group exposed to paint solvents including xylene, polyurethane, and others.

V. HUMAN HEALTH EFFECTS AND TOXICOLOGY OF ORGANIC SOLVENTS AND CHEMICALS

A. Introduction

The organic solvents comprise a large group of compounds (alcohols, ketones, aliphatic and aromatic saturated and unsaturated hydrocarbons, halogenated hydrocarbons, ethers, glycols, aldehydes, etc.) that are useful in industry because of their ability to dissolve and disperse greases, fats, oils, waxes, paints, varnishes, rubber, and many other materials. Common organic solvents used in aircraft maintenance currently and in the recent past include trichloroethylene, 1,1,1-trichloroethane, toluene, xylene, acetone, methyl ethyl ketone, isopropyl alcohol, freons, Stoddard solvent, and methylene chloride. Solvent exposures may occur not only in the workplace but in the home, including hobbies, and through deliberate abuse by inhalation of solvents ("sniffing").

Specific health effects for some individual solvents are well known: carbon tetrachloride may cause hepatic and renal failure; benzene causes aplastic anemia and acute and chronic myeloid and erythroid leukemia; carbon disulfide, methyl chloride, and methyl bromide may induce a toxic encephalopathy; methyl alcohol may cause retinal toxicity; and peripheral neuropathy has been reported after exposure to n-hexane, methyl n-butyl ketone, and carbon disulfide.

Most organic solvents share common toxic effects, most notable are those on the central and peripheral nervous system. The depressant narcotic effects of organic solvents have long been recognized; several compounds (chloroform, trichloroethylene) have been used as anesthetic agents. Early prenarcotic effects are dizziness, headache, slight incoordination, absentmindedness, nausea, paresthesia, increased perspiration, tachycardia, and hot flushes. These symptoms are mostly subjective and transitory, and their causal relationship with solvent exposure has, therefore, often been overlooked. Once the worker leaves the worksite, the body burden of solvents is depleted through exhalation and metabolism with subsidence of the prenarcotic symptoms. With exposure to higher concentrations or with longer exposure, more marked incoordination and a subjective feeling of drunkenness may occur. The risk of accidents is increased even with early prenarcotic symptoms, and more so with more pronounced symptoms.

The long-term effect of repeated episodes of slight prenarcotic symptoms is largely unexplored; it should be noted that symptoms are an expression of functional change in some cortical neurons. Repeated functional changes may lead to permanent impairment of some neuronal functions, possibly related to membrane and neurotransmitter changes. Neuronal loss is also a possibility; since no regeneration of neurons occurs, this can result in permanent neurologic damage. The diffuse nature of such effects would make their detection difficult, since no major well-localized neurologic deficit would signal the pathologic process. Behavioral signs of toxicity may occur after repeated exposures to solvents that do not occur after one or a few exposures. Since solvents are fat-soluble, they are absorbed by myelin sheaths surrounding the nerve fiber. There is a paucity of information on the persistence and microchemical effects of various solvents at these sites.

Repeated excess exposure to organic solvents may result in the gradual development of persistent symptoms (lasting several hours after cessation of exposure) such as headache, tiredness, fatigue, dizziness, irritability, loss of appetite, intolerance to alcohol, sleep disturbances (insomnia, hypersomnia, awakening after falling asleep, nightmares), and loss of libido and/or potency. These symptoms, often reported by workers with repeated solvent exposure, have received relatively little attention. A "psychoorganic syndrome" or "toxic encephalosis" have been terms used to refer to this syndrome.[1]

Most research on the neuropsychological effects of solvents has been done by Swedish and other Scandinavian scientists and reported in the past 5 years. Except for a conference proceedings by NIOSH on behavioral toxicology, relatively little research has been reported on the human neuropsychological effects of organic solvents in the United States.[2] The types of tests that have been most frequently used include questionnaires particularly for symptoms, standardized psychological tests, psychomotor tests evaluating various reaction times, tests of peripheral nerve function including electromyograms (EMGs)and electroneurography for nerve conduction studies, clinical neurological exams (vibration sense threshold, absent reflexes, etc.), electroencephalograms (EEGs), and occasionally others (e.g., computerized tomography scanning of the brain). These tests have been administered to clinical patients with "solvent poisoning" and to workers on cross-sectional epidemiologic studies. The cross-sectional studies have compared results to an unexposed referent population and have attempted to assess exposures both qualitatively and quantitatively. Most exposures have been mixed and substantially below recommended TLVs.

Acute, subacute, and chronic phases of neuropsychological effects have been described. Common symptoms following acute exposure to solvents are transitory intoxication, fatigue, poor endurance, and inability to concentrate. There may be feelings of unrest and slight depression, as well as neurological symptoms, such as dizziness, tremors, and balance disturbances. Headache, nausea, and vomiting occur if the exposure increases. In many cases, the person, a few hours after exposure, feels more sleepy and then sleeps longer and more deeply than usual. A worker who has been exposed acutely may become symptom-free over a weekend. If exposure to the solvent ceases, the intoxication effects and influence on alertness, the dizziness, and balance disturbances disappear. The symptoms of reduction in intellectual and emotional functions, however, may persist. The chronic syndrome is characterized by a neurasthenia whose central feature is psychological fatigue. The fatigue takes the form of poor endurance, loss of concentration, memory, and receptive ability, and an irritable depression. At this point, psychological performance tests show deterioration in coordination, speed, alertness, and concentration; these effects may be detected subclinically and, in some instances, before the individual is aware of the deficits. In Scandinavia, it has been generally accepted that exposure to solvents may lead to permanent invalidism.[3]

B. Clinical Toxicology: Uptake, Distribution, Biotransformation, and Elimination of Solvents

In understanding the biological effects of solvents, it is essential to know their clinical toxicology: absorption through the lungs, gastrointestinal tract, and skin; how they are distributed to various parts of the organism; biotransformation (metabolized); storage; and elimination. The coefficients for distribution of the solvents absorbed between air, blood, and various organs are known only to a limited extent. The values determined are largely from experimental studies, with few experiments performed on workers under typical working situations. A substance that is readily soluble in blood is absorbed to a larger extent in the lungs from inhaled air and reaches a higher concentration in the arterial blood than a poorly soluble substance under otherwise similar conditions.[4] A high concentration in arterial blood means, for those substances which can pass the blood-brain barrier, that there is risk of a higher concentration also in the central nervous system. Many solvents have a high affinity for fatty tissue and may be stored there for varying periods of time, thus affecting a redistribution of the solvent. A substance with a high distribution coefficient for fat/blood, and which also is slowly metabolized, is stored to a large extent in the fatty tissue during long-term exposure. Fat persons absorb more solvents than thin persons. The total uptake in humans through the lungs, as well as the alveolar, arterial, and venous concentrations, has been studied at rest or after a short time at work for some solvents: toluene, xylene, styrene, methylene chloride, 1,1,1-trichloroethane, trichloroethylene, and white spirit.[4,5] The total uptake of all of the substances increases more during work than during rest, at least at the beginning of exposure.[4] The uptake across the alveolar membrane increases up to 6 times more during heavy work than during rest for substances that are readily soluble in blood and tissues, (e.g., styrene and xylene), and twice for less readily soluble substances.[4] Elimination also occurs in the lungs for many solvents where the solvent is exhaled unchanged, although only a fraction of the total amount inhaled is eliminated through this mechanism.[6,7] Total uptake is determined best by measurements of concentrations in alveolar air and inspiratory air during exposure and estimations of pulmonary ventilation.[4] It should be noted that volatile substances like solvents may be present in the air in widely varying concentrations in different parts of one and the same workplace. Measurements of solvents in inspired and expired alveolar air have been done with gas chromatography for methylene chloride, trichloroethylene, styrene, xylene, toluene, and aliphatic/aromatic white spirits.[4,8]

Absorption may also occur through the intact skin and through the skin that may be altered by the solvent directly.[9] The penetration rate through damaged or diseased skin is generally much higher than through normal skin, and high skin temperature and high moisture also contribute to higher absorption. Most of the common solvents are absorbed through the skin without damaging the corneal layer, e.g., if both hands were immersed in xylene, the same amount would be absorbed over a given period of time as inhaling air containing 100 ppm xylene.[3] Generally, percutaneous absorption is small because of gloves and protective clothing.

1,1,1-trichloroethane and methylene chloride are poorly soluble in blood, while styrene and xylene are easily soluble.[5] Styrene and xylene are also stored in fat, with a half-life for styrene of 2-5 days.[5]

Biotransformations consist of 1 or more chemical reactions catalyzed by enzymes in the soluble (cytoplasmic), mitochondrial, or microsomal (endoplasmic) fraction of the cell. The reactions may be divided into 4 main types: oxidation, reduction, hydrolysis, and conjugation.[5] Oxidative reactions are usually located in the microsomal fraction and catalyzed by cytochrome P-450 dependent enzymes.[10] This enzyme can be induced in the liver by certain solvents, e.g., xylene and toluene. The toxicities of many chemicals may be manifested by intermediaries following biotransformation (referred to as "metabolic activation").[11] Biotransformation primarily leads to the formation of more water-soluble compounds that can more easily be excreted into the urine or bile than the substance itself.

The appearance of a harmful effect in a particular organ may be due to the existence of different metabolic paths in various parts of the body. This is exemplified by p-xylene, which causes a considerable reduction in the cytochrome P-450 level of the lung (toxic effect), but does not affect the cytochrome P-450 concentration of the liver. The cause is that a reactive metabolite, p-tolualdehyde, in the liver is quickly detoxified via aldehyde dehydrogenase, while the absence of this enzyme in the lung causes toxic effects in that organ.[12,13]

Humans absorb about 53 percent of the amount of toluene inhaled; about 18 percent of the amount absorbed is excreted in unchanged form via the air exhaled, while only small amounts (0.06 percent) of toluene are excreted in the urine.[5] About 80 percent of the amount taken up is changed to benzoic acid, which is then conjugated with glycine and excreted as hippuric acid in the urine.[14] Toluene in the blood and urine hippuric acid have been recommended as biologic monitors, although little research has been performed to correlate these with exposure. About 65 percent of xylene is taken up through the lungs and the principal metabolites (>95 percent) are isomers of methyl benzoic acid.[15] Hippuric acid in the morning urine collected at the end of a working week has been found to correlate with mean exposure during the 3 preceding days.[15] The chlorinated hydrocarbons, (carbon tetrachloride, chloroform, and 1,2-dichloroethane) all have toxic intermediates.[5] 1,1,1-trichloroethane is dechlorinated to a small extent and is mainly excreted through exhalation, although small amounts of metabolites, trichloroethanol, and trichloroacetic acid are found in the urine.[16] Induction of the cytochrome P-450 system in rats increases the hepatotoxicity of 1,1,1-trichloroethane, suggesting that a toxic intermediate may be formed.[17] Approximately 55 percent of trichloroethylene is absorbed following inhalation with small amounts of trichloroethanol and trichloroacetic acid found in the urine.[5] Trichloroacetic acid has been measured in the blood of workers exposed to trichloroethylene.[5] The P-450 system transforms trichloroethylene to an epoxide, which is rapidly hydrated to chloral hydrate, a well-known sleeping potion and CNS depressant.[5] Induction of the hepatic cytochrome P-450 system may enhance the hepatic injury caused by trichloroethylene.[18]

Primary alcohols are oxidized by alcohol dehydrogenase in the liver to aldehydes and, thereafter, to carboxylic acids and conjugated to glucuronic acid and sulphate. The secondary alcohols are oxidized to ketones. Methanol is metabolized to formic acid (formate), which is probably responsible for the retinal toxicity and metabolic acidosis caused by this compound.[19] The toxic agent phosgene has been detected in the metabolism of chloroform.[20]

Methyl n-butyl ketone and n-hexane are metabolized by the cytochrome P-450 system to 2,5-hexanedione, which is strongly neurotoxic.[21-24] Outbreaks of peripheral neuropathy have been reported among workers exposed to both solvents.[24] The hexacarbon neuropathies are distal axonopathies, representing a "dying-back" phenomenon. Unsteady gait, difficulty in gripping and holding heavy objects with the hands, and numbness in the arms and legs betray the insidious onset of distal pareses and anesthesia. Loss of tactile, pain, and temperature sensations are early findings. The symptoms may progress despite removal from exposure. Methyl ethyl ketone may potentiate the toxicity of methyl n-butyl ketone.[25] However, methyl n-butyl ketone has not been used at Hill AFB. In one outbreak in a Columbus, Ohio, printed fabrics plant, there were 86 verified cases of distal polyneuropathy among 1,157 employees surveyed.[24]

The metabolism of a number of the solvents is dose-dependent. Solvent-solvent or drug-solvent interactions are important because alcohol is well-known to potentiate the hepatotoxic effects of carbon tetrachloride and chloroform.

C. Neuropsychological Effects of Organic Solvents

Seppäläinen from the Institute of Occupational Health in Helsinki recently reviewed the neurophysiological findings among workers exposed to organic solvents.[26] She stated that the usual symptoms complained of by workers were headache, vertigo, a feeling of drunkenness, poor memory, and insomnia or other sleep disturbances. Long-term solvent exposure in persons with subjective complaints oftentimes had EEG changes.[27] The EEG has been linked with computer-assisted methods of analyzing spontaneous electrical activity of the brain and evoked potential techniques. The latter refers to the study of brain activity elicited by external stimuli like light, sound, or other sensory stimuli. Evoked potentials are so low in amplitude that they are completely masked by spontaneous electrical activity; their latencies and forms can be studied with computerized averaging, which improves the signal-to-noise ratio. She stated that telemetric EEG signals were altered among German workers with acute and long-term exposure to trichloroethylene; these changes were probably related to lowered vigilance.[26] She summarized the neuropsychological test results on 233 workers exposed to organic solvents and complaining of symptoms. There were 3 exposure groups: I, low-level or occasional (53); II, intermediate (113); and III, high and close to the TLV (67). There was a statistically significant increase in abnormal EEGs (70 percent) in group III compared to either groups I or II.[28] Group III also had greater abnormalities in the nerve conduction velocities compared to groups I and II.

The Institute of Occupational Health in Helsinki has also conducted an extensive research project on the neuropsychological effects of solvents used by car painters.[29] They studied 102 car painters from 27 car repair garages with a mean age of 35 years and mean exposure of 14.8 years to about 10 solvents at levels of 31.8 percent of the mixed current TLV. They were age-matched to 102 railroad engineers. Abnormalities in the maximal motor and/or sensory conduction velocities and/or motor distal latencies were found in 20 percent of the car painters (12 out of 59 subjects) versus none in the 53 referents similarly studied. The neurological exam found slight deficits to pain and light touch among car painters, but only changes in vibratory sense correlated with conduction velocity measures. The sense of vibration had been affected in the lower extremities of 65 of the 102 car painters and in 25 of the referents.[30] Both cases and referents had about one-third abnormal EEGs; usually only 10 percent of a population sample have abnormal EEGs, causing the authors to speculate on whole-body vibration or other factors responsible for the high rate among railroad engineers. The same study groups were evaluated with a test battery for intelligence, memory, personality, and psychomotor performance.[29] Impairments in visual intelligence (Block Design Test) and verbal memory and a reduction of emotional reactivity were the central features of the adverse effects of solvent exposure. The battery of tests used was comprehensive (Wechsler Adult Intelligence Scale (WAIS) - Similarities, Picture Completion, Block Design, Digit Span, Wechsler Memory Scale - Logical Memory and Associate Learning, Benton Test for Visual Reproduction and Retention, Santa Ana Dexterity Test, and various reaction times). The verbal memory tests measured the ability to concentrate on spoken verbal material and to keep it in mind; these tests may also be a measure of distractability rather than poor memory. There were no significant differences in the mean reaction times between the exposed and nonexposed, which was considered important because concentrations of toluene above 200 ppm after acute and long-term exposure had been found to slow reaction times.[31] The study group had increased subjective symptoms in addition to impairment of memory and concentration, suggesting that the exposed had a relative inability to keep rapport with the environment.[30,32] These changes suggested a reduced resource to cope with various demands of everyday life. In addition, a questionnaire sent to 124 men who changed jobs in the 5 years before the study revealed that health was an important reason for having left the car painting trade for those who had taken jobs without exposure to organic solvents.[32] An analysis of symptom differences found fatigue, concentration difficulties, and disturbances in vigilance more common in the painters; symptoms during the workday included irritation and prenarcotic-type complaints. There was a high statistical difference for answers to the question "Do you easily misunderstand orders given to you?"[32]

In addition to car painters and referral patients with solvent exposures, the Institute of Occupational Health in Helsinki has studied 98 laminators exposed to styrene and 206 workers exposed to carbon disulfide in the viscose rayon industry; several of their reports are intercomparisons of neuropsychological findings on these groups.[33,34] Symptoms of fatigue, difficulties in concentration, and symptoms of irritation occurred significantly more often in the styrene group compared to unexposed controls.[33] During the workday, irritation and prenarcotic symptoms, e.g., nausea, dizziness, and a drunken feeling, were also significantly more frequent. However, these symptoms did not correlate with urinary mandelic acid levels (a metabolite of styrene). Disturbance in visuomotor accuracy and, to a lesser degree, psychomotor performance were detected by neuropsychologic testing in the styrene group and the results correlated with urinary mandelic acid concentration. Lindstrom compared the styrene workers to 56 solvent-poisoned patients from their occupational medicine clinic, finding decreases in the WAIS Digit Span, Digit Symbol, Block Design Symmetry Drawing, Santa Ana Dexterity, and Mira Test among the latter.[34] The solvent-poisoned group was characterized by a decline in visuomotor performances and tests indicating freedom from distractability.

Lindstrom then evaluated the results of 5 different Finnish studies (car painters, solvent-poisoned, carbon disulfide, styrene-exposed, and painters exposed to toluene).[35] Of intellectual functions, visuoconstructive abilities (WAIS Block Design and Picture Completion) were altered among patients with solvent poisoning, car painters, and viscose rayon workers. Short-term memory was impaired in all except those exposed to styrene. Perceptual speed and accuracy measured in reaction time and dexterity tests were reduced in all groups. Multivariate analyses applied to the test battery in each of the 5 groups revealed several tests would form a combination with greatest statistical power in separating solvent-exposed from unexposed.[35] Car painters exposed to solvent mixtures had widespread impairment of cognitive functions and lowered motor speed, whereas those exposed to only a single aromatic hydrocarbon, toluene, and styrene showed only slight decrements.

In describing the emerging picture of solvent poisoning, Seppäläinen analyzed the neurophysiological and psychological test results of 107 patients with long-standing (mean 9.6 years for males and 7.6 years for females) occupational exposure.[36] There were 70 of 107 abnormal EEGs,usually consisting of excess slow waves in the waking record. A total of 17 out of 31 men and 31 of 46 women had at least one abnormally slow nerve conduction velocity. The frequency of subjects with abnormal conduction velocities tended to increase with higher exposure levels. When comparing solvent-poisoned to an age-matched Finnish standardization sample on the WAIS, significant differences were found for the solvent-poisoned on the Digit Span, Digit Symbol, and verbal tests. There were poor correlations between the neurophysiological and psychological tests. Of interest, the women had a more marked and wider range of decline in psychological variables than the men.

Swedish investigators have corroborated the picture of solvent poisoning depicted by the Finnish, using similar study approaches. They have also evaluated symptoms and neuropsychological tests on workers exposed to jet fuel and various solvent mixtures in the painting trades. Axelson and workers began with a case-control study, finding a risk ratio of 1.8 for nonspecific neuropsychiatric disorders among pensioners who had worked as painters, varnishers, and carpetlayers and were exposed to organic solvents.[37] A dose-response relationship seemed to exist between exposure in terms of occupational years and neuropsychiatric conditions.

One of the earliest studies evaluated 29 aircraft workers exposed to jet fuel (gasoline and kerosene) over 5 or more years compared to unexposed referents.[38] There were 13 high-exposed and 16 low-exposed. All of the high-exposed and 7 of the 16 low-exposed stated that they repeatedly experienced acute effects (dizziness, respiratory tract symptoms, heart palpitations, chest pressure, nausea, and headache) from the jet fuel vapors. Twenty-one workers complained of one or more chronic neurasthenic symptoms. Seventeen workers had symptoms of polyneuropathy and 77 percent of the high- and 44 percent of the low-exposed had signs of polyneuropathy in neurological examination. There were no significant decrements in nerve conduction velocities, but the nerve action potentials were smaller and there was a tendency toward higher vibration thresholds of the exposed group. A psychiatric interview, EEG, and a battery of psychological tests were administered.[39] Only 3 psychological tests showed differences (attention and sensorimotor speed), and there were no differences regarding memory or manual dexterity function. The EEGs had only slight differences--the exposed group showed, on average, a lower amplitude and a less observable rhythmic activity than the control group.

Swedish investigators have also studied house, car, and industrial painters.[40,41] A cross-sectional study of house painters identified a random sample of 52 from union records to compare to 52 unexposed age-matched referents.[40] Psychological tests assessing visual-logical ability and psychomotor coordination were reduced, but there was no correlation with duration of employment. Symptom complaints of the house painters included memory impairment, fatigue, and personality changes of an asthenic type. Elofsson et al. have reported a comprehensive study of 80 car and industrial spray painters compared to 2 reference groups with 80 subjects in each.[42]

There were 46 psychiatric items, 18 psychological tests, computerized EEG, electroneurography, vibration thresholds, quantified neurological examination, and a computerized tomographic brain scan. Statistically significant differences were found in the psychiatric examination consistent with a neurasthenic syndrome, in psychological tests with respect to reaction time, manual dexterity, perceptual speed, and short-term memory, and in peripheral nerve functions, particularly the long, sensory fibers. Exposure levels in 1980 and in a reconstructed paint booth of the 1955 period revealed solvent exposures considerably below current TLVs at both times. It should be noted that these authors specifically stated that the painters did not give impressions of overstating their complaints.[41]

Neurobehavioral effects of trichloroethylene and 1,1,1-trichloroethane are of considerable interest because of their extensive use patterns in aircraft repair and general industry as organic solvents, particularly in degreasing operations. The latter chemical has replaced the former because of suspect carcinogenicity of trichloroethylene in animal bioassays. Trichloroethylene and alcohol combined have been shown to profoundly affect depth perception and hand steadiness in a dose-effect manner, but no interaction for narcotic effects was seen.[42] Telemetered EEGs of workers exposed to trichloroethylene over a week revealed duration and amplitude increases of alpha waves from unexposed to exposed periods, but this might have been due to other factors such as work tedium rather than trichloroethylene.[43,44] Reaction times showed a deterioration when done over a workday among workers exposed to >100 ppm trichloroethylene, whereas they showed no change with workers exposed to <100 ppm, and the reaction times of controls improved over a workday.[45] Several case reports have shown cranial nerve deficits in workers exposed to trichloroethylene, especially of the trigeminal nerve; others have implicated a metabolite, dichloroacetylene, as being responsible for the neuropathy.[46] Feldman et al. have reported that a 26-year-old man investigating a degreaser leak was acutely exposed to trichloroethylene vapors for 1-1/2 hours and developed profound neuropathies: bilateral facial paralysis, constricted visual fields, diplopia, anesthesia of the face, and abnormal sensory nerve conduction in the ulnar nerve.[46] Follow-up 13 years later revealed that he had suffered a personality change and had lost his previously successful business. He had persistent difficulty in solving multiple-step problems and making business decisions—these deficits escaped formal testing techniques. In an animal study, effects of trichloroethylene on the central nervous system were revealed by 1,1,1-trichloroethane exposure after trichloroethylene exposure had ceased, suggesting a persistent trichloroethylene sub-threshold effect.[47]

In a review of the neuropsychological effects of industrial toxins, Feldman stated, "Chronic exposure to certain pollutants or byproducts of industry may result in behavioral changes in workers even before they are aware that the hazards exist or that they are being exposed."[48] He cited Salvani et al. who found decrements in tachistoscopic perception, manual dexterity, complex reaction time, and memory (Wechsler Memory Scale) in volunteer subjects exposed to average vapor concentration of trichloroethylene of 110 ppm (TLV 100 ppm).[49] Stewart et al. initially reported decrements in coordination and attention in normal volunteers exposed to trichloroethylene vapor in varying concentrations for 1,2, or 8 hours per day during a week's time, but they were unable to replicate Salvani's earlier work.[50] Stopps and McLaughlin reported dose-effect curves for 2-3/4 hours of exposure to 100, 200, 300, and 500 ppm of trichloroethylene, measuring human manual dexterity, perceptual reversals, card sorting, and a modified reaction time task.[51] Their data indicated an appropriate TLV would be in the vicinity of 100 ppm.

There are several case reports of deaths from acute exposure to 1,1,1-trichloroethane resulting in depression of the central nervous system, but 1,1,1-trichloroethane is considered one of the less toxic members of the chlorinated aliphatic hydrocarbon solvents. A case has been reported of mild transient neurological symptoms (dizziness) immediately following 1,1,1-trichloroethane exposure in a confined space, followed by hepatic and renal damage 2 days later.[52] He had proteinuria, a reduced creatinine clearance, jaundice, abnormal liver function tests, histological changes in the hepatocytes on liver biopsy, and a positive macrophage inhibition test to 1,1,1-trichloroethane, suggesting hypersusceptibility, and subsequently recovered.

Neuropsychological reports of workers exposed to 1,1,1-trichloroethane have reported conflicting results. Salvani et al. exposed subjects to 450 ppm for 24-hour periods and found no significant effects on perception, reaction time, or manual dexterity, whereas Gamberale et al. reported adverse effects on similar psychophysiologic functions after exposure to an average vapor concentration of 350 ppm.[53,54] Four baboons had no adverse effects at 350 ppm in performing a simple match-to-sample discrimination task, but had difficulty at

700 ppm that worsened at 1,400 and 2,100 ppm.[55] An important negative study, albeit a small sample, evaluated 22 female workers exposed only to 1,1,1-trichloroethane for a mean of 6.7 years at 3 exposure levels ranging from 110 to 345 ppm, with 1 worker exposed to 990 ppm.[56] No significant difference was observed between the exposed and unexposed females with respect to clinical features, maximal motor conduction velocity, conduction velocity of slow fibers, and psychometric data. The authors stated that the increase in headache, anxiety, and neurasthenic complaints may relate to unfavorable work conditions.

Toluene has also been evaluated experimentally in human studies. In exposure chambers, human volunteers inhaled 200 ppm toluene for 8 hours with resulting definite impairment of coordination and reaction time, which may render affected persons unsafe to both themselves and the industrial operation.[57] With higher concentrations, the effects became increasingly severe and, with concentrations of 600-800 ppm, adverse effects were observed after a few hours of exposure. Gamberale and Hultengren reported human reaction time and perceptual speed to be impaired by 20-minute exposures to toluene at 100, 300, 500, and 700 ppm, with a TLV in the vicinity of 100 ppm toluene.[58]

Organic solvents and ethanol or mind-or mood-altering drugs may have similar and interactive effects on the central nervous system. A degreaser's flush has been noted in workers exposed to trichloroethylene who then drink ethanol; erythematous, occasionally raised lesions on the face, arms, and trunk and facial flushing and dizziness characterize the transient phenomenon.

Ethanol is known to inhibit drug metabolism acutely and to stimulate drug metabolism through microsomal induction when administered repeatedly. Thus, the effects of ethanol on solvent metabolism may be complex. Ethanol blocks the metabolism of methanol and ethylene glycol to acetaldehyde (toxic metabolite). Ethanol decreases the metabolic clearance of trichloroethylene 2- to 3-fold and m-xylene, while reducing urinary metabolites of these compounds.[3,59] Individual variation in response to these multiple exposures has been described.

Another example of a chemical-chemical interaction occurred when workers exposed to isopropyl alcohol were accidentally exposed to carbon tetrachloride and 14 became ill, including 4 with renal failure or toxic hepatitis.[60] Acetone, a product of isopropyl alcohol metabolism, is a potentiator of carbon tetrachloride toxicity.

Methylene chloride is used as a paint stripper and degreaser with a unique metabolic fate.[61-63] Stewart et al. reported that individuals exposed to methylene chloride in a paint-and-varnish remover had an elevated carboxyhemoglobin level with no apparent carbon monoxide exposure.[61] In studies with human volunteers, these authors showed that carboxyhemoglobin levels of 5.0 percent resulted from 3 hours of exposure to 250 ppm of methylene chloride.[61] Stewart and Hake reported that similar levels could be reached following exposure to paint and varnish remover.[62] These levels of carboxyhemoglobin have been shown to stress patients with underlying cardiac pulmonary disease and 3 myocardial infarctions, including death following paint stripping in a basement, have been reported.[62] Furthermore, the levels of carboxyhemoglobin persist longer than after exposure to CO, because the absorbed methylene chloride is released slowly from storage in body tissues to be metabolized to CO; the addition of solvents such as methanol to paint stripper mixtures further prolongs the metabolism of methylene chloride to CO. Putz et al. compared the effects of CO and methylene chloride on performance tasks, concluding that each substance in concentrations sufficient to produce a carboxyhemoglobin concentration of 5 percent impaired performance under difficult or demanding task conditions.[64]

Neuropsychologic changes have also been reported due to methylene chloride: depression, sleep disturbances, irritability, and disturbances of vision.[65] Psychomotor performance has been found to be impaired at exposure levels below 400 ppm. One recent case-control neuropsychological study reported no evidence of long-term damage that could be attributed to exposure to methylene chloride.[66] However, an earlier German case report found a toxic encephalosis in a 39-year-old chemist working in a pharmaceutical factory.[67] He used methylene chloride several hours a day for 5 years in an unventilated room.

Solvents probably affect the CNS and PNS adversely by altering transport across nerve membranes.[3] There may be alterations in gamma amino-butyric acid, an important neurotransmitter in the CNS. Irreversible injury has also been reported: brain atrophy has been noted in Danish and Finnish studies.[68,69] Degeneration of the hypothalamus and optic tract were found in cats who drank 2,5-hexanedione, the toxic metabolite of n-hexane and methyl n-butyl ketone.[70] The cats became quadriparetic after 2-3 months' exposure, and a lesion resembling Wernicke's disease in humans was noted histologically (involvement of mamillary bodies, anterior cerebellar vermis, gracile nuclei, and peripheral nerves, resulting in ataxia and loss of recent memory in humans). Schaumburg and Spencer concluded, "Prolonged, low-level exposure to hydrocarbons in the environment may cause premature deterioration in areas of the human brain vital for perception and behavior."[70]

Little is known about the time frame and processes of healing in the PNS and CNS following exposure and detection of an adverse effect. It may well happen that chronic symptoms, possibly due to irreversible changes, improve and may even be regarded from the clinical viewpoint as cured--although this is probably not the commonest course of events. The healing process means that other (undamaged) parts of the brain can gradually be trained to take over the functions that have been diminished. The EEG may detect abnormalities at this stage, despite the fact that the EEG monitors only about one-fifth of the brain.[3] However, the types of abnormalities have differed among investigations, e.g., Seppäläinen found increased theta activity, whereas Rosen found an increase in beta activity in exposed persons.[71,72] Behavioral signs of toxicity may occur after repeated exposures to solvents, which do not occur after one or a few exposures (cumulative effect).

Neuropsychological testing has detected additive effects (e.g., trichloroethylene and methyl chloroform) and synergistic effects. For example, when rabbits are exposed to trichloroethylene and styrene, disturbances in balance occur with concentrations that are 10 times lower than when they are exposed to each solvent separately.[3]

D. Teratogenesis, Carcinogenesis, and Mutagenesis By Organic Solvents

Benzene is generally considered a leukemogen and, with the discovery of the carcinogenicity of vinyl chloride, other chlorinated hydrocarbons, particularly with similar asymmetrical chemical structures such as vinylidene chloride and trichloroethylene, became suspect. Furthermore, several of the compounds were mutagenic in various assays such as the Ames test, and others exhibited mutagenic intermediates when liver microsomal enzymes were added to the test system. Benzene and vinyl chloride have also been associated with chromosomal abnormalities in occupationally exposed populations.[73,74]

In a study of grease-removers who had been exposed to trichloroethylene, a high incidence of chromosome anomalies was observed in peripheral lymphocytes.[75] Laboratory and printing workers with mixed solvent exposure showed an increased incidence of chromatid and isochromatid rupture.[76]

Trichloroethylene, tetrachloroethylene, dichloroethane, carbon tetrachloride, and chloroform have all shown carcinogenic effects in conventional tumor-induction tests on mice or rats.[3] Epidemiologic studies on persons exposed to trichloroethylene have generally found no increase in cancer incidence in relation to those expected.[3,77] However, the report by Peters et al. and others raise the question whether exposure to solvents in the aircraft industry may result in increased cancer incidence among the workers' offspring.[78] Furthermore, brain cancer may be related to chemical exposure, including those considered among organic solvents.[79]

Male and female mice fed high levels of trichloroethylene 5 days per week for 78 weeks (males 1,169 to 2,339 mg/kg; females 869 to 1,739 mg/kg) revealed a significant increase in hepatocellular carcinoma compared with nonexposed matched and colony controls.[3,80] Rats on a similar regimen did not experience an increase in cancer incidence. Also, 1,1,1-trichloroethane has been found to be mutagenic in Salmonelli typhimurium strain TA 100, with or without microsomal activation.[81] Forni et al. investigated chromosome changes in rotogravure workers exposed to toluene for 3 to 15 years at levels near the TLV.[82] The exposed workers showed a higher rate (0.83 percent) of chromosome breaks compared to controls, but the differences were not statistically significant. Further negative evidence was provided by Haglund et al.,who found no differences in chromosomal aberrations or sister chromatid exchanges among 17 painters and matched referents exposed primarily to toluene and xylene.[83]

E. Effects on Other Organs

Most of the organic solvents may be irritating to the eyes, nose, and throat. Repeated skin contact may produce a dry, scaly, fissured dermatitis due to the solvent's defatting properties. Solvents, with their fat-dissolving qualities, dry out the skin and facilitate the development of allergic and toxic eczemas. This, in turn, may facilitate the uptake of other substances through the skin, apart from being a problem itself.

Acute cardiac rhythm disturbances are known to occur with some solvents, e.g., sudden death after exposure to fluorocarbons, 1,1,1-trichloroethane, and trichloroethylene, or the increase in cardiac sensitivity to adrenaline after exposure to tetrachloroethylene and chloroform.[84,85] The increased incidence of ischemic heart disease in cases of long-term severe exposure to carbon disulfide is known, but the mechanisms of action are unclear.[3]

Numerous solvents may cause an acute effect on the liver with excretion of certain enzymes, and most solvents that cause hepatic damage may also cause necrosis. Examples include ethyl alcohol, carbon tetrachloride, 1,1,2,2-tetrachloroethane, tetrachloroethylene, trichloroethylene, styrene, chloroform, and other chloroethanes.[3]

Solvent exposure has also been associated with chronic glomerulonephritis and Goodpasture's syndrome.[86-88] Studies have generally used the case-control approach, with increased histories of potential exposures among cases compared to controls. An immunologic mechanism has been speculated.

Some solvents might contribute to respiratory airways' hyperreactivity or an occupational asthma. An example is the irritating chemical formaldehyde, which has been documented to cause airway hyperreactivity.[89]

Solvents may also cause irritation of the conjunctiva and may possibly affect the clarity of the cornea or lens of the eye.[90] A maculopathy has been described in the retina following n-hexane, and methanol classically produces retinal toxicity.[19,91]

Renal tubular acidosis and hypokalemia with myopathy have been associated with toluene sniffing.[92] A recent case series report of 25 adults poisoned by toluene sniffing showed 3 different clinical patterns: muscle weakness with hypokalemia, gastrointestinal complaints including abdominal pain, and neuropsychiatric disorders including altered mental status and peripheral neuropathy. Danish investigators have found elevated serum creatinine kinase in 69 patients prospectively examined for solvent-related effects compared to

96 nonexposed referents.[93] The workers had no weakness or electromyographic abnormalities, and the abnormally high chemistries dropped to normal after removal from exposure. Alcohol intake was similar in both groups.

An epidemiologic-clinical study of 151 matched pairs exposed to a daily mean of 115 ppm 1,1,1-trichloroethane and unexposed textile workers found no differences for blood chemistry and hematologic parameters except serum glutamic-pyruvic transaminase and albumin.[94]

What effect organic solvents may have, if any, on the immune system is an area of virtually no information. Since solvents may affect the hypothalamus in animal studies, there may be effects by solvents on the pituitary hormones.[3]

Table 9 lists relative toxicities to various organs and biological functions by selected organic solvents. T9

REVIEW OF MORBIDITY TEST PROCEDURES THAT COULD BE USED IN CLINICAL-EPIDEMIOLOGIC EVALUATIONS OF EXPOSED WORKERS

A. Neurobehavioral Tests

The following overview of behavioral tests is from a book chapter, "Behavioral Toxicology", by Drs. Barry L. Johnson and W. Kent Anger, NIOSH, in the textbook, Environmental and Occupational Medicine, Rom WN (Editor), Boston, MA., Little, Brown and Company, 1983. This list is meant to be comprehensive rather than selective. Selection of the various tests depends on the symptoms and signs of those exposed and the past literature on the compound(s) being studied or those with similar chemical structures. The tests of behavior can be divided into 2 categories: 1) questionnaires/personality tests, and 2) performance tests. Questionnaires/personality tests address what people say about themselves, whereas performance tests measure what they are able to do.

Questionnaires/Personality Tests

Questionnaires that have been used in worksite evaluations are listed in Appendix 2. Based on the focus of the tests, the questionnaire/personality tests may be further subdivided into 3 groupings that identify: a) symptomatology suggestive of neurological problems; b) feelings or affect; and c) personality variables. The questionnaire produced by the Finnish Institute of Occupational Health is the broader of the two listed in Appendix 2 and has been used in several settings.

A2

Tests that differentiate mood or feeling have been used in several worksite evaluations. The Multiple Adjective Affect Checklist consists of adjectives such as fearful, loving, or disgusted, which the subjects select as being either descriptive or not of their psychological state. The Feeling Tone Checklist, developed by the United States Air Force, consists of such descriptive phrases as "about to drop", to which the subject is to respond whether he or she feels "worse than", "the same as", or "better than" the phrase. One questionnaire, though not validated, purports to assess lability and extroversion. The data in column 5 of Appendix 2 indicate that questionnaires have been relatively useful in differentiating between exposed and nonexposed populations, but it is likely that any of a variety of factors (e.g., administrative pressure at work) apart from the chemical exposures of interest could have been a causative agent, thus reducing the predictive value of these tests.

The Manifest Anxiety Scale was designed to assess anxiety that chronically pervades one's personality (rather than being situational in nature). Four personality scales listed are standardized psychological tests designed for the detection of abnormal personalities. The Eysenck Personality Inventory assesses the construct of neuroticism through questions about the existence of food aversions, body sway in response to the suggestion of falling, the length of time the respondents can hold their breath, and other matters. The MMPI assesses such variables as psychopathy, excessive concern with bodily functions, paranoia, obsessions or compulsions, bizzare thoughts, and hyperactivity.

The Rorschach is far less structured than the tests outlined above, and a trained professional is required for its administration, as well as its evaluation. The test uses carefully chosen inkblots to allow the person to project his or her personality through descriptions of what he or she sees in the inkblots. Ability to attack a problem, the strategy used in attacking the problem, flexibility, and emotional control are interpreted from their responses, along with feelings of tension, anxiety, inadequacy, and depression. While it has been suggested that personality variables may be affected by toxic chemicals, it is unlikely that the considerable time required to conduct and evaluate such tests is justified by the return in cases where there is not reason to suspect such changes.

Performance Tests

Performance tests can be divided along traditional psychological divisions of a) sensory tests, b) motor tests, and c) tests of complex function and memory. There is a certain degree of overlap in that sensory and complex tests require some motor output to indicate the receipt of the input, and motor tests are cued by sensory input. Perhaps the most difficult distinction lies between sensory tests of pattern recognition and complex function tests of memory. In each case, the judgment on categorization is based on the primary evaluative function.

Sensory tests. These tests are primarily directed toward visual function, although tests of audition and tactile sensitivity have been used. Tests of visual sensory function are referenced in the first 12 entries in Appendix 3. A3 Tests of visual resolution or acuity are all standardized, and each has substantial normative data. Tests 1 through 3 require the subject to distinguish gaps or spatial separations of various sizes between lines. Two-flash fusion and flicker-frequency tests consist of presenting two short-duration flashes of light with different intervals of time between their presentation. The intent is to determine the threshold point for a fused appearance of light. The test of depth perception requires the subject to determine which of two stimuli is positioned at a greater distance, while the test of accommodation forces the person to focus on circles at different distances, with 0.3-5 seconds between presentations and report where there is a break in the line forming the circles. The tests of peripheral vision provide flashes of light at various points in the periphery around the person's field of view to determine the outer boundaries of this visual field. The test of color vision requires arrangement of buttons of different hue and saturation in an order based on their similarity.

Tests of pattern discrimination are distinguished from sensory tests on the basis that processes beyond the level of the sensory organ's response are involved. There are a variety of pattern discrimination tests each of which requires the subject to view a pattern or figure and a) decide if a second figure is the same or different, b) to select a similar figure, c) to draw the figure, d) to report or describe the pattern. In some of these cases, memory is a significant factor. Two tests are directed toward naming familiar figures embedded in a set of distracting lines.

The Neisser Letter Search and the Bourdon-Wiersma tests are each categorized as tests of speed as well as pattern discrimination, due to the requirement that they be performed quickly, but they also require the subject to strike out letters or sets of dots with a pencil, so figure or number identification is involved. Tests 34 and 35 (Appendix 3) are classical vigilance tasks, requiring the subject to monitor a series of light flashes or presentations and respond to differences in rate or pattern.

There have been relatively few auditory evaluations. Standard Audiometric tests have been used in which the threshold level of audibility for different pure tone frequencies has been measured. These tests use self-reporting procedures where the listener adjusts the sound level of a test tone to, in effect, trace his own hearing thresholds. Another type of test, the tone decay test, requires the subject to report when a continuous tone set at the threshold level is no longer heard. The extent to which the intensity must be raised to re-establish its audibility provides a measure of tone decay. Three tests of tactile sensitivity have been used, although two were not described in the reports. Test 41 combines a test of finger steadiness and proprioceptive feedback in which the subject must press a spring-loaded button and attempt to maintain a constant pressure.

These sensory tests, taken together, provide a fairly thorough and accurate assessment of visual and auditory sensory processes, and the tests of visual pattern discrimination clearly call into play cortical brain centers. The fact that so few tests listed in Appendix 3 detected deficits in the examined populations (see column 5) is likely reflective of the relatively low exposure levels found in the industrial settings evaluated, rather than sensitivity of the tests.

Motor tests. The motor tests require some sensory input in the form of a stimulus to cue the response but, unlike the sensory tests that manipulate the stimulus to determine the sensitivity of the observer, the motor tests emphasize the speed or accuracy of responding.

Motor tests of strength employ a dynamometer in which the subject grips a handle and pulls against a spring; a strain gauge measures the stength of the pull (Appendix 4). Finger and arm steadiness have been studied, using strain gauges or electrode/accelerometer arrangements to detect movement; movement is converted to a direct-current (dc) voltage, and the voltage changes are analyzed. A4

A large variety of tests of coordination have been used. Rail balancing requires both coordination and a functioning sense of balance. Blind toe-pointing accuracy was not described but is procedurally obvious. The Symmetry Drawing Test requires a subject to draw (symmetrically) the unfinished half of simple figures, such as a tree. Subjects are instructed to draw straight and zigzag lines without visual feedback in the Mira Test. Pencil-flipping speed simply involves tossing and catching a pencil 25 times, as rapidly as possible. The tapping tests consist of the subject tapping his or her toe or finger as many times as póssible in a fixed duration. Tests of simple reaction time typically involve two buttons, one which the subject presses when ready to respond, and the other which is pressed when some cueing stimulus is presented. The subject's task is to release the first button and press the second as quickly as possible. The Santa Ana Dexterity Test consists of square pegs placed in square depressions in a base plate and requires the subject to lift, turn 180 degrees, and reinsert as many pegs as possible in 30 seconds. The Michigan Eye-Hand Coordination Test consists of a base plate with a series of 119 1/8 inch-diameter holes. A stylus must be placed in each hole successively, and the speed of moving through all 119 holes is measured, as well as the variability in interhole movement times. Choice reaction time simply provides 2 or more potential responses and associated stimuli, requiring the subject to discriminate the onset of a stimulus and then to choose the appropriate response.

A number of tests of steadiness, coordination, and speed plus coordination have successfully detected untoward exposures in worksite testing. These reflect the debilitating motor effects caused by the chemicals used by the work groups selected for study. However, the motor tests cannot be said to adequately test neuromotor integrity with any approximation to the thoroughness found in sensory testing. This reflects the state of behavioral testing, as well as the large number of widely distributed muscles and their attendant nervous system input found in human beings.

Complex Function and Memory. A variety of standardized tests of complex functions and memory have been used in worksite test projects, and these are listed in Appendix 5. The test of time estimation requires that the subject A5
press a hand-held switch and hold it depressed sufficiently long to match the duration of a previously presented tone. Both dual tasks engage the subject in a constant monitoring of performance task and require a second performance at irregular intervals. The tests of mental arithmetic require simple addition or addition and subtraction, each under some time pressure. Both speed and accuracy are measured. The digit-symbol subtest of the Wechsler

Adult Intelligence Scale (WAIS) requires the subject to match a set of digits with a set of symbols, using a coding key to indicate the appropriate matches. In the block design subtest of the WAIS, the subject views a red-and-white design and constructs that design using blocks that have sides that are red, white, or red and white. On occasion, the entire WAIS, or a significant segment of it, has been administered as a test of intellectual performance in rating toxic effects. The WAIS consists of 11 subtests that require well over an hour for administration by an individual trained in its use. The Raven Progressive Matrices Test presents a series of progressively more difficult diagrams with missing elements; the subject is to select the cor- one from a set of possible missing elements.

Although most tests of memory are largely from the WAIS, the first one listed is a complex combination of verbal abilities and recall that could be categorized under visual testing or intelligence testing, as well as under memory. The digit-span subtest of the WAIS consists of oral presentation by the examiner of sets of 3 to 9 digits, and the subject is instructed to repeat them back to the examiner in either the same or reverse order. The longest string of digits correctly repeated both forwards and backwards is used as the measure of memory. The Wechsler Memory Scale consists of 3 subtests of the WAIS: the digit span, logical memory (recall of elements of a story), and visual reproduction (drawing of a figure from memory). The tests of memory involving a distraction each consist of a stimulus presentation followed by an arithmetic task or a counting task, after which the subject is asked to recall the initial stimulus.

Considerations in Cross-Sectional Neurobehavioral Studies. In proposing studies, the following things need to be taken into consideration: the symptoms and signs reported by exposed workers; the hypotheses proposed; the literature on previous epidemiological, experimental, or animal studies on the chemical or similar chemicals to be studied; and confounding variables such as alcohol consumption, communication among potential study subjects about the tests, etc.

The bulk of the tests cited above suffer from lengthy test duration and the lack of automation or potential for automation. While these tests, particularly those from the WAIS, are among the foremost standardized tests of intellectual function, they may not be representative of the extent or depth of complex intellectual function, as little is understood of such functions.

There is a large number of problems inherent in the employment of behavioral tests in human worksite studies that need to be mentioned. The problems relate to the application in workplace studies of behavioral tests and their interpretation. The foremost problem is the matter of selecting reference groups. Correlations between exposure and assessment of possible behavioral effects are not fully interpretable unless a properly chosen reference group is available for comparison.

Also related to the use of reference groups is the problem of biologic significance. A result that appears statistically significant may not be biologically significant--it may be an artifact of the tests. For example, it is possible that all workers from a given worksite may exhibit the same behavioral effect, due to the presence of factors other than those directly measured. The best way to control for such a possibility is to employ a suitably chosen reference group. Ideally, the reference group would match (age, sex, education, employment history, etc.) the experimental group, with the exception that the latter group has been occupationally exposed to the toxic substance(s) under evaluation. Upon completion of the study, the investigator is in a position to evaluate the effect and significance, if any, of the toxic substance on behavior.

It is important to maintain known, constant conditions throughout the testing sessions. One should ensure an adequately lighted, noise-free environment to the extent possible. Within the room used for testing, distractions to the subject must be minimized. Partitions formed by cloth hospital dividers will separate subjects adequately. If many persons are being tested on a battery of behavioral tests, it is essential to have a means for controlling traffic by subjects and others through the testing area. When a battery of tests is being administered, it is important to plan equal subject-testing time for each station, to prevent queuing at any one station.

One of the most important factors requiring control by the investigator is specific practice on the test. Comparisons are best made between groups of subjects that are equal in practice and whose performance is at least past the initial rise of the practice curve when the curve is steep. Very few behavioral tests have small practice effects. In particular, measurements of temporal characteristics of performance, e.g., latency, tend to change over extended periods of practice. Accuracy measures may plateau and then resume an increasing trend. Standardization may be achieved either by giving the groups the same number of trials on the test or by bringing the subjects within the groups to a common level of achievement. Neither method is very practical for workplace testing, since there is no way to control the worker between trials, nor is there sufficient testing time to provide even a moderate amount of practice.

Insofar as possible, the experimenters should be unaware of the exposure or treatment history of each person evaluated, in order to avoid investigator bias. The order of testing of workers should be randomized.

There are some controllable factors that may mimic toxic effects. Simple fatigue is one such example. Ideally, all subjects should be tested in the same state of alertness, physical fitness, etc. The best procedure is to test each participant at the same time of day and to use a self-administered fatigue rating scale. The fatigue measures can then be used as independent variables in various statistical analyses.

Other confounding factors, such as drugs, substance abuse (particularly alcohol), and various disease conditions, are potential problems. The effects of these factors on behavior can be difficult to factor out from effects due to workplace exposure to a toxic substance. The preferred method is to delete participants with such conditions from the study.

As described in the previous section, one limitation of behavioral testing is the lack of specificity of the results. Not only may observed impaired behavioral results be due to fatigue or drugs, but even if these factors are controlled, one often may not be sure what workplace condition--or combination of conditions--caused the impaired performance.

B. Neurological, Neurophysiological, and Neuroradiological Examination Methods

1. Neurological Examination

The clinical neurological examination needs to be performed by a neurologist, preferably one, in a standardized format. The clinical examination should classify loss of function in 3 (none, slight, marked impairment) degrees as regards special cranial nerve senses, discriminatory skin sensitivity, joint kinesthesia, sensitivity to touch, temperature and pain, muscle reflexes, muscle strength, tone, and coordination.

2. Electromyography (EMG)

Through the application of EMG, it is possible to obtain quantitative information concerning the integrity of the motor unit, sensory nerve, and some spinal pathways. Electrical stimulation of peripheral nerves permits evaluation of nerve conduction and provides an assessment of the number of axons conducting in the nerve. Loss of motor neurons or axonopathy results in decreased amplitude and changes in the wave form of the evoked muscle action potential. Segmental or demyelinative neuropathies produce profound slowing of motor nerve conduction velocities and marked desynchronization of the arrival of motor nerve impulses, causing prolongation of the muscle action potential. Axonopathy may affect the sensory nerves primarily. Temperature-dependent conduction velocities can be determined in peripheral sensory nerves. Slowing of velocity and decreased amplitude of the nerve action potential are indicators of neuropathy. Computer averaging techniques are used to detect very small action potentials. Conduction in proximal segments of spinal nerves can be determined by obtaining F-waves. These are late-arriving potentials following the direct motor response, which occurs from antidromic activation of motor neurons. H-reflex studies are used to evaluate the integrity of the monosynaptic reflex. Ia muscle afferents are stimulated, and homonymous motor neurons are activated through a single synapse. The response has been shown to be the equivalent of the tendon jerk. Thus, all components of peripheral nerve, as well as large fiber systems in the dorsal and ventral roots, can be evaluated quantitatively by means of EMG. The technique is applied in an effort to determine the distribution, extent, and degree of involvement of the neuromuscular system.

Through the use of stimulators capable of delivering 2 stimuli at various intervals, absolute and relative refractory periods of sensory nerve can be determined. The refractory period evaluates the excitability cycle of peripheral nerve. Influences upon axonal membrane conductance may be reflected in changes in the excitability cycle. Normal values for sensory nerve are available. In alcoholic, diabetic, and uremic neuropathy, the relatively refractory period is a significantly more sensitive indicator of neuropathy than is maximum conduction velocity.

The needle electrode examination assesses the response of skeletal muscle to processes causing a loss of muscle fibers or motor units. Characteristics of motor unit action potentials are altered by these processes. Such features as the rate of discharge (rate coding), recruitment, amplitude, duration, and wave form all provide information with respect to motor unit pathology. Spontaneous activity such as fibrillations, positive waves, myotonia, fasciculations, etc. are helpful in the diagnosis of denervation and other disorders that affect sarcolemmal membrane excitability. Which muscles are examined and the thoroughness of the evaluation are crucial to detection of early mild abnormality.

Neuropathy may be present and easily detectable by clinical examination in the absence of symptoms. For example, a considerable degree of intrinsic foot muscle atrophy and proprioceptive deficit can be present in an asymptomatic individual. Distal sensory loss and areflexia may be discovered in an asymptomatic patient. Under these circumstances, the EMG examination is likely to reveal gross abnormality of peripheral nerve and muscles. Involvement of large sensory neurons is especially likely to yield findings of abnormal sensory nerve conduction in a patient who may manifest only mild proprioceptive defect.

The technique of EMG is highly standardized, and normal values are available for all of the major peripheral nerves. The nerve is stimulated at proximal and distal sites, and the recording electrodes are placed over small muscles of the hands or feet. Distal intramuscular and neuromuscular junction delays are eliminated by subtraction of distal from proximal latencies. This difference is divided into the distance between the 2 sites of stimulation. Supramaximal stimuli are used and latency measurements are taken to the first negative liftoff, thus evaluating maximum conduction speed. Direct latency measurements are made for sensory nerves. Special techniques to obtain F- and H-wave responses are applied to evaluate the proximal components of spinal nerves. Refractory periods are determined at the time nerve conduction studies are done. Results are temperature-dependent and require adjustment of skin temperature to above a critical level.

Toxicants present in the workplace can produce neuropathy that is not symptomatic. The distribution, extent, and severity of the neuropathy are not predictable. This emphasizes the importance of performing a thorough evaluation that includes nerves of upper and lower extremities, as well as proximal and distal locations.

3. Electroencephalography (EEG)

The EEG is the commonest neurophysiological method to study cerebral function. The limitations of the EEG may be seen from the fact that only about one-fifth of the total cerebral cortex is directly accessible to examination. The EEG frequency wave spectrum changes with degree of alertness and depth of sleep. Most brain diseases result in slower-than-normal electrical activity. The EEG changes corresponding to the depth of anesthesia and metabolic comas are well known, but those resulting from chronic, recurrent exposures to toxins, including chronic alcoholism, may be minimal, even when gross neurological deficits can be demonstrated. Although little would be expected among workers exposed to chronic, low levels of solvents, most studies show deviations from the controls, although the types of changes in the different studies are conflicting. Quantitative objective analyses of the spectral content of the EEG might resolve some of these differences.

The scalp-recorded EEG is analyzed according to the amount of electrical activity within specific frequency bands, specifically delta (1/2-4 Hz), theta (4-8 Hz), alpha (8-13 Hz), beta 1 (13-20 Hz), and beta 2 (20-30 Hz). Electrical potentials recorded from brain tissue in response to external sensory stimuli are called sensory-evoked potentials. A series of sensory-evoked potentials, when averaged, is called the average-evoked-potential; this is indicative of the neural activity of the brain involved in the processing of sensory input. A tendency to delayed response or increased latency in solvent-exposed persons using the visual evoked response (VER)—not a surprising finding in view of the well-documented slowing of nerve conduction velocity in the similar population at risk.

4. Roentgen Computer Tomography (C-T Scan)

The C-T scan permits examination of the structure of the brain and its ventricles without necessitating the injection of air into the ventricles or of contrast medium into the cerebral arteries. At least 2 studies detected cerebral atrophy in persons exposed to solvents, while a third did not. This latter study was done on healthy, asymptomatic workers, and the authors could not rule out a mild cerebral edema in the exposed. The C-T scan involves less radiation than a skull series of x-rays, but the machinery is not portable.

Rapidly developing tests, such as nuclear magnetic resonance and position emission tomography, may be most sensitive in detecting metabolic changes in the cerebri of solvent-exposed subjects.

C. Tests for Teratogenesis, Carcinogenesis, and Mutagenesis

A variety of short-term tests have been devised to investigate the mutagenicitiy of substances.[95] The most widely used and standardized of these is the Ames test.[96] It uses special strains of salmonella, which , because of a stabilized mutation, are dependent for growth on histidine. Mutagenic agents will induce reverse mutations, so that some of the bacteria can grow without histidine. The end point can then simply be a counting of colonies on histidine-deficient media. This basic test has been modified by using strains with other mutations in order to minimize DNA repair and to make the cell wall more permeable. Microsomal enzymes from rat liver are usually added to activate indirect carcinogens, as metabolic activation may be minimal in bacterial systems. Similar tests using E. coli, B. subtilis, yeast, and paramecia have been developed, using both forward and backward mutations.[97]

Although bacteria share with higher organisms certain universal genetic features, they are phylogenetically remote from mammals. For this reason, as well as differences in metabolism, research on mutation has been done increasingly with mammalian cell systems.

DNA synthesis inhibition tests using a variety of mammalian cells can be used to distinguish between toxic agents that injure DNA and those that do not.[98] DNA repair activity can be measured by alkaline elution, hydroxy-apatite fractionation, gradient centrifugation, autoradiography, and by scintillation counting of the unscheduled incorporation of radioactive DNA precursors. The demonstration of DNA repair following the treatment of cells with a specific agent (unscheduled synthesis) indicates that the agent has induced DNA lesions.

Cytogenetic effects of mutagenic agents in mammalian cell systems can be determined by cell transformation assays, micronucleus tests, conventional metaphase analysis of chromosome spreads, and sister chromatid exchange methods. A number of different cell types are used in these methods, including Chinese hamster ovary cells, lymphoma cells, HeLa cells, and rat liver cells. When these techniques are extended to intact animals, including man, the usual cells studied are lymphocytes from peripheral blood, bone marrow cells, or skin fibroblast.[99]

The Sister Chromatid Exchange (SCE) test has revolutionized the cytogenetic approach to the identification of biologically active compounds. The SCE test consists of a differential staining of one of the pair of chromosomes so that any interchange of genetic material between duplicated regions (chromatids) is immediately apparent on examining the standard chromosome spread.[100] While the impact on the cell of such interchanges may be small, the SCE test is a relatively simple, highly sensitive, quantitative index of chromosomal damage by physical and chemical mutagens. In contrast with gross chromosome aberrations, which are usually associated with cell death, SCE appears to reflect DNA injuries that are compatible with cell survival. The SCE test is usually applied to cells exposed in vitro, but is applicable to in vivo exposures.

Animal test systems have great appeal because bacteria and cell systems lack the complexity of metabolism, hormonal levels, tumor promoters, anti-promoters, etc. of intact animals.[97] Bacterial and animal systems are combined in the liver perfusion and host-mediated bioassay. The agent to be tested and the test organism are injected into the animal and, after a specified period, the test organism is withdrawn and checked for mutations. Although these tests may reflect both in vivo activation and deactivation, they are quite organ specific, and several incubation sites may be needed to avoid false negatives.

Dominant lethal tests are usually done with mice.[97] Recessive lethal tests are usually done with drosophila. In mice, males are treated with the suspect agent and mated at specified time intervals. Females are then dissected in midterm of pregnancy and checked for corpora lutea, preimplantation loss, early deaths, and living fetuses. The test measures fertility, but its major limitation is that it can only detect mutations that do not affect the fertilizing ability of the sperm bearing them.

In the Heritable Translocation Test, males (usually mice) are treated and mated.[97] Both the F_1 and F_2 generations are then evaluted for sterility and semisterility. If a reduction in litter size occurs, cytological techniques are used to identify translocation figures in the dividing spermatocytes. Again, the principal limitation is that selective elimination may occur before the spermatogonia-bearing translocations reach the spermatocyte stage, thus minimizing the frequency of detectable translocations.

D. Determination of Sample Size

The determination of sample size depends on the estimated outcome rates in the exposed and unexposed groups, the degree of statistical power ($1-\beta$ error) and significance desired (α error). The formula for the sample size determination is as follows:[101,102]

$$n = \frac{\left[C_{\alpha/2}\sqrt{\overline{P}(1-\overline{P})} - C_{1-\beta}\sqrt{Pe(1-Pe) + Pc(1-Pc)}\right]^2}{(Pc - Pe)^2}$$

Where n is the required sample size for each group, $C_{\alpha/2}$ and $C_{1-\beta}$ denote the value cutting of the standard normal curve associated with α and β error. For example, $\alpha = 0.05$, then $C.05/2 = C.025 = 2.242$. Pe and Pc denote the anticipated outcome rates in the exposed and unexposed groups, respectively. $\overline{P}$ is 1/2(Pe + Pc).

The approach of this formula assumes that it is planned to make a test of significance of the difference between the 2 outcome rates. For the exposed group, the expected outcome rate will be estimated based on the relative risk in consideration of the outcome rate of the unexposed group. For example, the incidence of spontaneous abortions is estimated as 0.15 in the general population, and the rate in the exposed group could be expected as 0.20, with a relative risk of 1.3.

The determination of β error depends on the degree of power. The criterion of β suggested by Cohen is that one can set β approximately equal to 4α, so that the power becomes, $1-\beta = 1-4\alpha$.[101] Thus, when $\alpha = 0.05$, β may be set at 0.20. Using a fixed number of samples from a 20 percent random sample, β error can be computed with α error, Pe, and Pc by the following formula:[103,104]

$$z_\beta = \frac{(Pc - Pe)\sqrt{n}}{\sqrt{Pe(1-Pe) + Pc(1-Pc)}} - z_\alpha$$

z_α and z_β are the normal deviate corresponding to the two-tailed probability α and β.

$$\beta \text{ error} = P(z_\beta)$$

Table 10 gives sample sizes for selected outcome rates of Pe and Pc with $\alpha = 0.05$ and $\beta = 0.20$. For example, if an observed frequency of neurological changes was expected to be 20 percent in the unexposed group and it was desirable to detect a 1.5-fold increase in the exposed group, then about 332 in each group would be needed to give 80 percent assurance. T10

If one should increase the power to 90 percent, then the sample sizes will be increased. For a neurobehavioral study, if one plans to use the total numbers (about 300) exposed to mixed high-level solvents from a 20 percent random sample, the statistical power will be over 80 percent, which is considered safe for data analysis. Most of the neurobehavioral studies in the literature have used less than 100 study subjects, which makes it difficult to evaluate the statistical significance of findings because of low statistical power.

I. SUMMARY AND RECOMMENDATIONS

A. Summary

1. The principal current exposures to toxic materials at Hill AFB are to various types of organic solvent chemicals, including 1,1,1-trichloroethane, methylene chloride, methyl ethyl ketone, Freon 113, toluene, xylene, alcohols, and acetone. In the recent past, other organic solvents contributed significantly to usage, e.g., trichloroethylene. Occupational exposures are often to several solvents in work processes and, on occasion, to a mixture of solvents in a trade-named solution.

The industrial hygiene monitoring and control of exposures was similar to that in the private sector over the past 4 decades. However, there are anecdotal incidences of overexposures including spills, solvent abuse, and passing out after exposure in confined spaces.

2. There is a large population of both potentially exposed and unexposed workers at Hill AFB that could be available for morbidity studies. Unexposed controls are available to match for age, sex, and probably education. A large number of workers exposed for 10 or more years are available for study as well as short-term (approximately 1 year) employees. Thus, chronic, subacute, and acute effects of occupational exposure to organic solvents might be studied. Industrial hygiene exposure data are available for the recent past and could be reconstructed backward in time for at least a decade.

A substantial portion of ex-employees and retirees remain in the local (Ogden) or regional (Salt Lake City) area and could be located. Ill-effects of exposure might be more prevalent in ex-employees or retirees who left work because of symptoms or illness.

3. Most of the health-related literature on organic solvents is recent, Scandinavian in origin, and demonstrates that the earliest and most sensitive toxic effects are neuropsychological. These studies purport to show a picture of organic solvent poisoning characterized by fatigue, dizziness, loss of recent memory, impaired psychomotor performance, and irritability. However, the majority of the research identifies subclinical impairments on psychological testing, nerve conduction velocities, and electroencephalograms. These results have been identified in case-control, cross-sectional studies usually to mixed solvents at exposures within and, in some reports, substantially below current TLVs. The studies have practically all been done on small populations (usually fewer than 100 exposed workers), and few have identified exposure-effect levels or a dose-response. Furthermore, correlations with metabolites of the solvents or other indices of exposure have been poor. A large (>500 subjects), randomized, cross-sectional study of neuropsychological effects of organic solvents typical of actual working conditions to identify chronic, subacute, or acute effects of exposure appears not to have been performed.

Clinical toxicology studies assessing absorption, distribution, biotransformation, storage, and excretion of organic solvents have been performed in a limited manner on most of the solvents, and human experimentation studies have been done on several. However, these studies have seldom been done under actual working conditions, particularly when the exposures are to several solvents concurrently or sequentially. There is little information on important interactions, such as methyl ethyl ketone enhancement of the neurotoxicity of n-hexane, or a variety of solvents delaying the excretion of methylene chloride prolonging the presence of carboxyhemoglobin.

Most of the solvents have been tested for mutagenicity and carcinogenicity in in vitro or animal bioassays. The halogenated compounds with asymmetric structures or unsaturated C-C bonds tend to form reactive intermediaries that may be the proximate cause of mutagenesis or carcinogenesis. Epidemiologic testing of workers for evidence of chromosome abnormalities is limited.

Few mortality studies have been performed to identify or quantify cancer mortality. Those studies that have been reported have been limited by small numbers, poorly documented exposure, or short latency periods.

Studies of the effects of solvents on other organ systems have generally been case-series reports (e.g., cardiac toxicity of 1,1,1-trichloroethane and trichloroethylene or renal toxicity of toluene sniffing) or retrospective case-control studies (e.g., glomerulonephritis and solvents). Worker surveys have often found elevated hepatic enzymes without any other clinical or laboratory abnormality, with the clinical significance left unaddressed.

4. Remarkable progress has been made in standardizing research methodologies to address the health effects of organic solvents. Psychological testing has been standardized; the roentgenographic brain-axial tomogram and EEG have been computerized; and peripheral nerve testing has become more sophisticated, with both motor/sensory parameters being evaluated. Statistical power can be estimated for the neuropsychological tests, with approximately 300 workers and 300 controls sufficient for a sample size to detect small differences.

B. Recommendations

1. The earliest and most sensitive human health effect of organic solvents is on the central nervous system and, to a lesser degree, on the peripheral nervous system (CNS/PNS). The brain's cognitive, emotional, and motor functions are essential to normal well-being and productive work, and any harm to this organ may be significant. Organic solvents differ significantly in their toxicities to the CNS/PNS, and interactions of mixtures are little known. A cross-sectional, randomized neuropsychological research study is feasible to detect clinical and subclinical effects of organic solvents. Possible examination tests include peripheral nerve testing, central nervous system (EEG), neurobehavioral tests, and questionnaires that are sufficiently developed and standardized to provide valid and reproducible results. Hill AFB is an excellent site for such research for the following reasons: 1) There are significant members of exposed and unexposed workers; 2) There are sufficient long-term employed workers to assess chronic, subacute, and acute effects of occupational exposures, and; 3) There has been state-of-the-art usage and control of organic solvents with adequate/good records of exposure. Furthermore, mixed exposures concurrently, sequentially, and changes in solvent use over time can be assessed using epidemiologic methods of stratification and biostatistical methods (logistic regression) to assess single-solvent effects and interactions (including additive and synergistic). We recommend that neuropsychological health research at Hill AFB be a high priority, that it is feasible, and that it is desirable for both management and union.

Industrial hygiene evaluation should be performed to correlate any medical findings to specific organic solvents or groups of solvents and to establish possible dose-response relationships.

Other types of research that could be considered include clinical evaluations of those workers who allege they are solvent-poisoned. Although this could describe the picture of solvent poisoning, this type of clinical observation is not new and, without a randomized sample and a reference group, could result in a biased picture.

If the null hypothesis of organic solvents do not cause clinical/subclinical neuropsychological abnormalities is disproven and significant subclinical effects are found, one may appropriately inquire as to what biological and clinical significance are the findings? The long-term effects of such abnormalities would be appropriate for further research. It would be important to determine the persistence of such findings and whether or not they may contribute to personality and family disorders, illness, or injury, longitudinally.

2. The second priority for research that we consider feasible are the cardiovascular effects of the commonly used paint stripper methylene chloride. Methylene chloride is metabolized in the human to carbon monoxide (carboxyhemoglobin), and the excretion of the carbon monoxide may be inhibited by other solvents. There are a large number of current, ex-, and retired employees who had potential exposures to this solvent.

3. Third, we consider research on the absorption and distribution of one or more solvents simultaneously, under actual working conditions

at Hill AFB, to be feasible. Correlations between current and past exposures and biological indicators are important research projects. Metabolism, storage (assessed by fat biopsy) and excretion can also be studied.[109] It is likely that intermediate products and minor metabolic pathways are of decisive importance from the toxicologic viewpoint. A variety of test parameters can be evaluated, e.g., level of physical exercise, body fat, age, and sex in the uptake and denouement of specific chemicals. Interactions with drugs, alcohol, smoking, and oral contraceptives are important.

4. The questions of teratogenesis, carcinogenesis, and mutagenesis are more vexing. Adverse reproductive outcomes currently can be assessed with a standardized questionnaire developed by NIOSH, and with a variety of tests to evaluate infertility (sperm penetration, sperm motility, morphology and count, endocrinologic tests, and so forth). Reproductive research is an important priority, but the research tools are only beginning to be applied, and priorities should be workers with a single exposure especially to suspect human mutagens and carcinogens.

The NCI is currently performing a mortality study at Hill AFB that addresses the question of carcinogenicity of organic solvents. The mortality study may identify other causes of mortality (e.g., ischemic heart disease, stroke, suicide) that might have an association with occupational exposure to solvents.

There is limited information on chromosomal tests in workers exposed to organic solvents. This type of research must control for other potentially clastogenic exposures (e.g., cigarette smoking, medical x-rays) and must have rigidly defined criteria for selection of the exposed and unexposed subjects. These tests are time-consuming, expensive, and technically difficult. Although there is a high correlation between mutagenicity and carcinogenicity, there is virtually no information that allows for prediction of cancer or teratogenicity risk from an abnormal chromosome test or an elevated sister chromatid exchange rate for an individual. The development of this type of information may have tremendous importance for occupational medicine. However, this type of information would probably be more predictive and cost-effective in studying a population of workers exposed to a known carcinogen.

5. An issue in the occupational safety and health concerns at Hill AFB is workers' compensation and liability. We recommend that any scientific research at Hill AFB be performed by impartial, competent academicians and scientists. They should not be involved in any consultations with either Hill AFB management or the AFGE union. Furthermore, they should not evaluate any patients or workers in an occupational medicine clinic or other setting that could involve a compensation or legal case regarding employment at Hill AFB. Thus, the investigators need to maintain an absence of any conflict of interest in order to produce objective, credible research results.

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Table 1

MAJOR CHEMICALS USED AT HILL AIR FORCE BASE 1970-1982

Chemical	Comments	Estimated Usage Per Month	Estimated No. of Workers Potentially Exposed
1,1,1-Trichloroethane	(1)	8,600 Gal.	2,500 (300 Vapor Degreasing)
Acetone		120 Gal.	200
Alcohols			
Ethyl Alcohol	(2)	206 Gal.	150
Isopropyl Alcohol	(3)	80 Gal.	150
Methyl Alcohol		80 Gal.	150
Chromium	(4)	900 Lbs.	10
Methylene Chloride	(5)	6,500 Gal.	600
Soldering Flux (does not include core solder)		20 Gal.	200
Hydrochloric Acid	(6)	3,100 Gal.	100
Methyl ethyl ketone	(7)	2,100 Gal.	1,700
Methyl iso-butyl ketone		10 Gal.	50
Paint Thinner	(8)	3,800 Gal.	200
Tetrachloroethylene	(9)	1,800 Gal.	20
Solvent (unspecified or Stoddard)	(10)	2,600 Gal.	400
Toluene (also possibility of benzene as a contaminant in earlier years)	(11)	1,100 Gal.	300
Xylene	(12)	60 Gal.	100
Chloroform	(13)	1978+ 5 Gal. 1970-78 20 Gal.	10 5

Table 1 (Continued)

Chemical	Comments	Estimated Usage Per Month	Estimated No. of Workers Potentially Exposed
Chromium Compounds			
Chromic Acid	(14)	1,300 Gal.	100
Zinc Chromate		270 Gal.	125
Nitroglycerin			100
Cyanide	(15)		
Nickel	(16)		50
Trichloroethylene	(17)	1978+ 0 Gal. 1970-78 6,000 Gal.	1978+ 0 1970-78 2,000
Freon TF	(18)		

(1) Approximately 70 percent used in degreasing tanks.

(2) TCE replaced some ethyl and isopropyl alcohol as a cold state solvent in 1958.

(3) (See comments under ethyl alcohol.)

(4) In use since 1968. Abrasive blasting parts and vacuum metallizing released dust during strut plating operations in the plating shop. Abrasive blasting parts of sanding released dust in the landing gear shop. Usage of chromium varied from approximately 2-7 people in the leading gear shop to approximately 10-50 people in the plating shop.

(5) Paint stripping involves about 50 people and represents about 90 percent of usage.

(6) Principally one dip tank in MANPR.

(7) Used in small quantities for part cleaning, except in corrosion control where large quantities were used for stripping paints. Usage varied from approximately 50-100 people. Also used by small industrial shops throughout Hill Air Force Base.

Table 1 (Continued)

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(8) Principal use (80 percent) is by aircraft preparation and maintenance unit (MANBSF) (approximately 175 people). Approximately 80 involved in disassembly and cleaning function.

(9) Principally a vapor degreaser in Building 507 (MANPGW).

(10) Approximately 45 percent used by MANBPSF and an additional 30 percent used by MANPB (armament repair section) (124 people).

(11) Approximately 70 percent used by MABPSF in Building 200

(12) Almost all used by MAX in Building 100 (85 percent plus).

(13) Chloroform was used from 1965 to 1978 and usage varied from approximately 25 to 50 people. Use was small, sporadic, with limited duration.

(14) Use has varied from 40 to 150 people. Currently used in dip tank in MANPGW (makers of brakes, disassembly, Building 507). Used in large quantities in paint spray booths. Exposure varied from 30 to 200 people.

(15) Used as a cold solution in plating tanks with exposures of 40 to 150 people.

(16) Nickel metallizing has been conducted since 1968. Usage varied from approximately 10 to 50 people for welding operations and approximately 10 people for nickel metallizing operations.

(17) Trichloroethylene was replaced as a general solvent in about 1968 with 1,1,1-trichloroethane. Usage was widespread throughout industrial shops, with exposure varying from 2,000 to 3,000 people. TCE degreaser tanks were replaced in about 1979 with 1,1,1-trichloroethane tanks. Approximately 15 to 20 vapor degreasers were in use at Hill from 1950 to 1970. Usage varied from 60 to 150 people.

(18) Thirty-five percent is used in Building 100 and 25 percent is used in Building 507; 16 percent is used in Building 510 = 78 percent.

Table 2

CHANGES IN THRESHOLD LIMIT VALUES (TLV's)
OVER THE PERIOD 1967-PRESENT (1982)
(8-hour time-weighted averages except as noted)

Substance	TLV (ppm) 1967	1972	1977	1982	OSHA-PEL (ppm)
1,1,1-Trichloroethane (methyl chloroform)	350			350	350
Trichloroethylene	100	100	100	50	100 - 8-hour TWA(1) 200 - ceiling (5 min in any 2 hours) 300 - peak
Xylene	100			100	100
Toluene	200	200(2)	100	100	200 - 8-hour TWA(1) 300 - ceiling (10 min) 500 - peak
Freon 113 (1,1,2-trichloro 1,2,2-trifluoroethane)	1,000			1,000	1,000
etone	1,000	1,000	1,000	750	1,000
MEK (2-butadine)	200			200	200
Isopropyl Alcohol	400			400	400
Methylene Chloride	500	500(3)	200	100	500 - 8-hour TWA(1) 1,000 - ceiling 2,000 - peak
Nitroglycerin	0.02(6)	0.20	0.20	0.02(4)	0.20(5,6)

(1) TWA - Time-weighted average concentration; ceiling - value that may only be exceeded for the time and frequency specified; peak - value that may never be exceeded.

(2) On intended changes list to 100 ppm.

(3) On intended changes list to 250 ppm.

(4) On intended changes list to 0.05 ppm.

Ceiling never to be exceeded.

Ceiling.

Table 3

FREQUENCIES OF EXPOSED AND CONTROL GROUPS OF CURRENT EMPLOYEES BY AGE, SEX, RACE, EMPLOYMENT DURATION, AND INCOME LEVEL

	Exposed Group		Control Group	
	Number	(%)	Number	(%)
Age groups (years)				
Total all ages	1396	(100.0)	1509	(100.0)
<20	1	(0.1)	18	(1.2)
20-29	215	(15.4)	198	(13.1)
30-39	547	(39.2)	356	(23.6)
40-49	303	(21.7)	441	(29.2)
50-59	269	(19.3)	415	(27.5)
60-69	59	(4.2)	77	(5.1)
≥70	2	(0.1)	2	(0.3)
Sex				
Male	1260	(90.3)	875	(58.0)
Female	136	(9.7)	634	(42.0)
Race				
White	1259	(90.2)	1413	(93.6)
Black	13	(0.9)	13	(0.9)
Hispanic	111	(8.0)	60	(4.0)
American Indian	6	(0.4)	5	(0.3)
Oriental	7	(0.5)	18	(1.2)
Employment duration (years)				
<1	105	(7.5)	151	(10.0)
1-5	433	(31.0)	420	(27.8)
6-10	262	(18.8)	184	(12.2)
11-15	172	(12.3)	124	(8.2)
16-20	226	(16.2)	277	(18.4)
>20	198	(14.2)	353	(23.4)
Income level (yearly)				
Low <$15,000	17	(1.2)	367	(24.3)
Middle $15,000-$24,999	1192	(85.4)	594	(39.4)
High ≥$25,000	187	(13.4)	548	(36.3)

Table 4

POTENTIAL STUDY GROUPS BY COMMONALITY OF EXPOSURE

Exposure Categories

A. 1,1,1-trichloroethane

   1. past trichloroethylene exposure

   2. vapor degreasers and dip tanks

B. Mixed low-level solvents

   1. toluene, xylene, freon, acetone, MEK, isopropanol, etc.

   2. Building 100 bench-type exposures

C. Methylene chloride

   1. paint strippers

   2. depotting activities

D. Painters

   1. mixed paint solvents

E. Aircraft mechanics

   1. intermittent confined space exposure

   2. small amounts of MEK, mostly 1,1,1-trichloroethane, some JP_4

F. Beryllium

G. Nitroglycerin

H. JP_4

   1. fuel dock workers

I. Welders

Table 5

NUMBER OF CURRENTLY EXPOSED EMPLOYEES IN THE VARIOUS
COMMONALITY OF EXPOSURE GROUPS IN THE 20 PERCENT SAMPLE

	Exposure Categories									
Exposure Level	A	B	C	D	E	F	G	H	I	TOTAL
Occasional		10	5		97					112
Low-intermittent	5	282	4	3	158		17	10		479
Low continuous		70	18	9					5	102
High-intermittent	50	24	80	11	87		3			255
High-continuous	9	14	6	3	1					33
Totals	64	400	113	26	343	0	20	10	5	981

Legend

Low = less than one-half the TLV

High = greater than one-half the TLV (but generally less than the TLV)

Table 6

FREQUENCIES OF EXPOSED AND CONTROL GROUPS
EX-EMPLOYEES AND RETIREES BY AGE GROUP,
RACE, EMPLOYMENT DURATION, AND INCOME LEVEL

	Exposed Group		Control Group	
	Number	(%)	Number	(%)
Age groups (years)				
Total all ages	305	(100.0)	404	(100.0)
20	1	(0.3)	37	(9.2)
20-29	54	(17.7)	94	(23.2)
30-39	61	(20.0)	52	(12.9)
40-49	29	(9.5)	35	(8.7)
50	160	(52.5)	186	(46.0)
Race				
White	267	(87.5)	357	(88.4)
Black	8	(2.6)	10	(2.5)
Hispanic	27	(8.9)	27	(6.7)
American Indian	1	(0.3)	3	(0.7)
Oriental	2	(0.7)	7	(1.7)
Employment duration (years)				
<1	31	(10.2)	97	(24.0)
1-5	53	(17.4)	66	(16.4)
6-10	36	(11.8)	30	(7.4)
11-15	30	(9.8)	21	(5.2)
16-20	21	(6.9)	19	(4.7)
>20	134	(43.9)	171	(42.3)
Income level (yearly)				
Low <$15,000	70	(22.9)	207	(51.2)
Middle $15,000-$24,999	210	(68.9)	117	(29.0)
High ≥$25,000	25	(8.2)	80	(19.8)

Table 7

NUMBER OF EXPOSED EX-EMPLOYEES AND RETIREES
IN THE VARIOUS 'COMMONALITY OF EXPOSURE
GROUPS IN THE 20 PERCENT SAMPLE

	Exposure Categories									
Exposure Level	A	B	C	D	E	F	G	H	I	TOTAL
Occasional		12			17					29
Low-intermittent		36	3		29		4	3		75
Low-continuous		10	1						3	14
High-intermittent	4	4	13		12					33
High-continuous	2	1	2	1						6
als	6	63	19	1	58	0	4	3	3	157

Legend

Low = less than one-half the TLV

High = greater than one-half the TLV but generally less than the TLV

Table 8

RESIDENTIAL LOCATIONS OF THE 10% RANDOM SAMPLES
OF THE EX-EMPLOYEES AND RETIREES

	Number	(%)
Number of 10% random sample*	70	(100.0)
Number of residents located within Utah	64	(91.4)
Number not located	6	(8.6)
Areas located in Utah		
Total	64	(100.0)
Ogden	38	(59.3)
Salt Lake City	4	(6.3)
Provo	2	(3.1)
Other areas	20	(31.3)

*10% random samples from a 20% sample (704) of the ex-employees and retirees

Table 9

RELATIVE TOXICITIES TO VARIOUS ORGANS/FUNCTIONS BY SELECTED ORGANIC SOLVENTS

	CNS	PNS	TCM	Heart	Liver	Kidney	Skin
1,1,1-trichloroethane	M	L	L	H	M	M	L
trichloroethylene	H	M	M	H	H	M	L
methylene chloride	H	M	M	H	M	M	L
freons	M	L	L	H	L	L	L
isopropyl alcohol	L	L	L	L	M	L	L
methyl ethyl ketone	M	M	L	M	L	L	L
toluene	M	M	L	M	M	H	L
xylene	M	M	L	M	M	M	L
acetone	L	L	L	L	M	L	L
chloroform	H	M	H	H	H	M	L

CNS = Central Nervous System

PNS = Peripheral Nervous System

TCM = Teratogenicity, Carcinogenicity, Mutagenicity

H = High (Effects Established)

M = Intermediate

L = Low (Minimal Effects Reported)

Table 10

SAMPLE SIZE NEEDED TO DETECT A DIFFERENCE IN THE FREQUENCY OF THE GIVEN OUTCOMES IN THE EXPOSED AND UNEXPOSED GROUP WITH A POWER OF 0.80

Outcomes to be Measured	Frequencies (rates) Exposed Group	Unexposed Group	Relative Risk	Significance Level (α)	Power (1-β)	Sample Size for Each Group
Neurobehavioral Abnormalities						
EEG Abnormality	0.30[a]	0.10	3.0	0.05	0.80	80
Abnormal Nerve Condition	0.20[a]	0.5	4.0	0.05	0.80	100
Neurological Changes (Symptoms and others)	0.30[b]	0.20	1.5	0.05	0.80	332
	0.28[c]	0.15	1.9	0.05	0.80	191
erse Reproductive comes						
Spontaneous Abortions	0.20[d]	0.15	1.3	0.05	0.80	901
Low Birth Weight (<2,000 gm)	0.14[e]	0.07	2.0	0.05	0.80	364
Birth Defects	0.04[e]	0.02	2.0	0.05	0.80	1,859
Mental Retardation	0.008[e]	0.004	2.0	0.05	0.80	7,090

[a] A mixture of organic solvents (28)

[b] Trichloroethylene exposure (105,106)

[c] Toluene exposure (107)

[d] Expected rates (108)

Appendix 1

JOB TITLES OF POSSIBLE EXPOSURE GROUP

(from 20 percent random sample)

	Job Title	Number
1.	Aircraft Freight Loader	7
2.	Aircraft Freight Loader Foreman	1
3.	Aircraft Freight Loader Helper	4
4.	Aircraft Freight Loader Inspector	3
5.	Aircraft Mechanic	116
6.	Aircraft Mechanic Helper	4
7.	Aircraft Mechanic Foreman	28
8.	Aircraft Electrical System Mechanic	55
9.	Aircraft Electrical System Helper	16
	Aircraft Electrical System Installer and Repairer	21
	ircraft Engine Mechanic	10
2.	Aircraft Engine Mechanic Foreman	1
3.	Aircraft Overhaul Foreman	1
4.	Aircraft and Systems Overhaul Foreman	6
5.	Aircraft Inspector	5
6.	Aircraft Worker	46
7.	Aircraft Helper	24
8.	Aircraft Components Inspector	3
9.	Aircraft Ordnance System Mechanic	14
0.	Aircraft Ordnance System Repairer	3
.	Aircraft Ordnance System Repairer Helper	5
2.	Aircraft Ordnance System Mechanic Foreman	1

Appendix 1

JOB TITLES OF POSSIBLE EXPOSURE GROUP
(Continued)

Job Title	Number
23. Aircraft Pneudraulic System Worker	2
24. Aircraft Pneudraulic System Mechanic	1
25. Aircraft Propeller Mechanic	1
26. Aircraft Missile Loader	1
27. Aircraft Missile Loader Foreman	1
28. Aircraft Refueling Vehicle Operator	10
29. Aircraft Refueling Vehicle Operatory Foreman	3
30. Airframe Jig Aligner	2
[illegible] Airfield Cleaning Equipment Operator	3
Automotive Mechanic	6
33. Automotive Mechanic Worker	1
34. Air Conditioning Equipment Mechanic	10
35. Battery Repairer	1
36. Blocker and Bracer Inspector	1
37. Blocker and Bracer Inspector Foreman	1
38. Boiler Plant Operator	8
39. Boiler Plant Operator Foreman	2
40. Boiler Plant Equipment Mechanic	5
41. Boiler Plant Equipment Mechanic Foreman	1
42. Bindery Worker	3
43. Crane Operator	3
Crane Operator Foreman	1

Appendix 1

JOB TITLES OF POSSIBLE EXPOSURE GROUP
(Continued)

	Job Title	Number
45.	Custodial Worker	6
46.	Cook	1
47.	Carpenter	4
48.	Construction and Maintenance General Foreman	1
49.	Digital Computer Mechanic	3
50.	Equipment Cleaner	5
51.	Electronic Mechanic	84
52.	Electronic Mechanic Helper	3
53.	Electronic Mechanic Foreman	1
	Electronic Worker	16
55.	Electronic Worker Helper	6
56.	Electronic Measurement Equipment Mechanic	14
57.	Electronic Measurement Equipment Mechanic Foreman	1
58.	Electronic Equipment Repairer	3
59.	Electronic Equipment Installation and Maintenance Inspector	1
60.	Electronic Integrated Systems Mechanic	28
61.	Electronic Integrated Systems Mechanic Foreman	3
62.	Electrician	13
63.	Electrician Foreman	2
64.	Electrical Equipment Repairer	7
65.	Electrical Equipment Repairer Foreman	2
66.	Electrical Equipment Worker Helper	1

Appendix 1

JOB TITLES OF POSSIBLE EXPOSURE GROUP

(Continued)

	Job Title	Number
67.	Electroplaster	1
68.	Electroplaster Foreman	1
69.	Electroplasting Worker	1
70.	Electroplasting Worker Helper	3
71.	Equipment Mechanic	10
72.	Equipment Mechanic Foreman	1
73.	Engineering Equipment Operator	2
74.	Food Service Worker	1
75.	Fork Lift Operator	2
	Fabric Worker	1
77.	Film Assembler Stripper	1
78.	Gardener	1
79.	Gardener Foreman	1
80.	General Equipment Examiner Foreman	7
81.	General Equipment Examiner	28
82.	Heat Treater	2
83.	Instrument Mechanic	71
84.	Instrument Worker	5
85.	Instrument Worker Helper	6
86.	Instrument Maker Foreman	5
87.	Laborer	31
	Locksmith	2

Appendix 1

JOB TITLES OF POSSIBLE EXPOSURE GROUP
(Continued)

Job Title	Number
89. Liquid Fuel Rocket Engine Mechanic	1
90. Liquid Fuel Rocket Engine Mechanic Foreman	1
91. Machinist	37
92. Machinist Foreman	2
93. Machine Tool Operator	7
94. Machine Tool Operator Helper	6
95. Material Sorter and Classifier	15
96. Material Sorter and Classifier Foreman	1
Material Expediter	28
Material Expediter Foreman	2
99. Maintenance Worker	3
00. Maintenance Worker Helper	1
01. Mechanic Parts Repairer	1
02. Meatcutter	1
03. Meatcutter Foreman	1
04. Meatcutting Worker	1
05. Meatcutting Helper	1
06. Motor Vehicle Operator	23
07. Motor Vehicle Operator Foreman	2
08. Mobile Equipment Metal Mechanic	1
09. Mobile Equipment Service	2

Appendix 1

JOB TITLES OF POSSIBLE EXPOSURE GROUP
(Continued)

	Job Title	Number
110.	Heavy Mobile Equipment Mechanic	6
111.	Heavy Mobile Equipment Mechanic Foreman	1
112.	Heavy Mobile Equipment Repair Inspector	1
113.	Nondestructive Tester	8
114.	Nondestructive Tester Foreman	1
115.	Nondestructive Tester Helper	3
116.	Ordnance Equipment Mechanic	15
117.	Ordnance Equipment Worker Helper	1
	Optical Instrument Repairer	2
	Offset Press Operator	3
120.	Pattern Maker	2
121.	Pattern Maker Foreman	1
122.	Packer	7
123.	Packer Foreman	1
124.	Plastic Worker	7
125.	Plastic Worker Helper	2
126.	Plastic Worker Inspector	1
127.	Plastic Fabricator Foreman	1
128.	Pipefitter	4
129.	Pipefitter Foreman	1

Appendix 1

JOB TITLES OF POSSIBLE EXPOSURE GROUP
(Continued)

	Job Title	Number
130.	Powered Support Systems Mechanic Foreman	3
131.	Powered Support Systems Mechanic	3
132.	Powered Support Equipment Repairer	1
133.	Powered Support Systems Condition Inspector	2
134.	Painter	10
135.	Painter Foreman	3
136.	Painter Helper	8
137.	Plumber	3
138.	Plumber Worker	1
	Plumber Helper	1
140.	Pneudraulic System Mechanic	22
141.	Pneudraulic System Mechanic Foreman	1
142.	Pneudraulic System Worker	7
143.	Pneudraulic System Worker Helper	7
144.	Pneudraulic System Repair Inspector	4
145.	Personal Flight Equipment Outfitter	2
146.	Personal Flight Equipment Outfitter Foreman	1
147.	Production Machinery Repairer	2
148.	Production Machinery Mechanic	7
149.	Production Machinery Mechanic Helper	1
150.	Production Machinery Mechanic Foreman	1

Appendix 1

JOB TITLES OF POSSIBLE EXPOSURE GROUP
(Continued)

	Job Title	Number
151.	Preservation Packager	12
152.	Preservation Packager Foreman	1
153.	Pest Controller	1
154.	Pest Controller Foreman	1
155.	Physiological Trainer Mechanic	3
156.	Printing and Reproduction Foreman	1
157.	Railroad Repairer	1
158.	Railroad Operation Foreman	1
	Railroad Conductor	1
	Roofer	1
161.	Rubber Equipment Repairer	1
162.	Small Arms Repairer	3
163.	Small Arms Repairer Foreman	1
164.	Sandblaster Helper	1
165.	Sandblaster	2
166.	Sheet Metal Mechanic	97
167.	Sheet Metal Mechanic Foreman	10
168.	Sheet Metal Worker	24
169.	Sheet Metal Helper	29
170.	Shot Peening Machine Operator	2
171.	Shot Peening Machine Operator Helper	1

Appendix 1

JOB TITLES OF POSSIBLE EXPOSURE GROUP
(Continued)

	Job Title	Number
172.	Toolmaker	9
173.	Toolmaker Foreman	1
174.	Tools and Parts Attendants	4
175.	Telephone Mechanic	2
176.	Telephone Worker	1
177.	Tractor Operator	6
178.	Utility System Operator	1
179.	Warehouse Worker	19
	Warehouse Worker Foreman	1
	Water Treatment Plant Operator	1
182.	Welder	7
183.	Welder Foreman	1
184.	Welder Helper	1
185.	Welder Inspector	1
186.	Wood Worker	9
187.	Wood Worker Helper	1
188.	Wood Worker Foreman	1
189.	Wood Crafter	4
190.	Worker Trainee	9
	TOTAL	1,396

Appendix 2 VERBAL TESTS

Test	Focus of Test	Chemical	Product, Industry, or Work Group	Effect Reported
1. Unnamed Questionnaire	Clinical Symptoms	Styrene/Methyl Ethyl Ketone	Fiberglas Boat Builders	Yes
2. "	Clinical Symptoms	Styrene	Polyester Plastics Mfg.	
3. "	Clinical Symptoms	Inorganic Lead	Storage Battery Mfg.	Yes
4. "	Clinical Symptoms	Carbon Disulfide	Viscose Rayon Workers	Yes
5. Unnamed Questionnaire	Clinical Symptoms	Multiple Chemicals	Pesticide Mfg.	Yes
6. Unnamed Questionnaire	CNS/PNS Symptoms	Inorganic Lead	Smelter Workers	Yes
7. Multiple Adjective Affect Checklist	Affect	Inorganic Lead	Storage Battery Mfg.	
8. "	Affect	Methyl Chloride	Foam Products Mfg.	
9. "	Affect	Inorganic Lead	Smelter Workers	Yes
10. Feeling Tone Checklist	Affect	Carbon Disulfide	Viscose Rayon Mfg.	
11. "	Affect	Perchloroethylene	Dry Cleaners	
12. Unnamed Questionnaire	Affect	Carbon Disulfide	Viscose Rayon Mfg.	Yes
13. Manifest Anxiety Scale	Anxiety	Organophosphates	Farmers, Applicators	Yes
14. Eysenck Personality Inventory (EPI)	Neuroticism	Inorganic Lead	Storage Battery Mfg.	Yes
15. Minnesota Multiphasic Personality Inventory (MMPI)	Personality	Polybrominated Biphenyls	Farmers	Yes

Appendix 2 VERBAL TESTS

Test	Focus of Test	Chemical	Product, Industry, or Work Group	Effect Reported
16. Edwards Personal Preference Schedule (EPPS)	Personality	Methyl Chloride	Foam Products Mfg.	
17. Clinical Analysis Questionnaire (CAQ)	Personality	Inorganic Lead	Storage Battery Mfg.	
18. Rorschach Inkblot Test	Personality	Carbon Disulfide	Viscose Rayon Mfg.	Yes
19. "	Personality	Styrene	Polyester Plastics Mfg.	Yes
20. "	Personality	Solvent Mixtures	Auto Painters	Yes
21. "	Personality	Carbon Disulfide	Viscose Rayon Mfg.	Yes

Appendix 3 SENSORY TESTS

Test	Focus of Test	Chemical	Product, Industry, or Work Group	Reported Effect
1. Orthorater	Visual Resolution	Inorganic Lead	Storage Battery Mfg.	
2. Vernier Acuity	Visual Resolution	Methyl Chloride	Foam Products Mfg.	
3. Landolt C-rings	Visual Resolution	Formaldehyde	Plywood Mfg.	
4. Two-Flash Fusion	Visual Resolution	Inorganic Lead	Smelter Workers	
5. Flicker Frequency	Visual Resolution	Carbon Monoxide	Toll Booth Operators	
6. "	Visual Resolution	Carbon Disulfide	Viscose Rayon Mfg.	
7. "	Visual Resolution	Perchloroethylene	Dry Cleaners	
8. "	Visual Resolution	Multiple Chemicals	Pesticide Mfg.	
9. Pointer Equality	Depth Perception	Formaldehyde	Plywood Mfg.	
10. Landolt C-rings	Accommodation	Formaldehyde	Plywood Mfg.	
11. Light Flash	Peripheral Vision	Formaldehyde	Plywood Mfg.	
12. Aimark Perimeter	Peripheral Vision	Multiple Chemicals	Pesticide Mfg.	
13. Button Comparison	Color Vision	Formaldehyde	Plywood Mfg.	
14. Farnsworth Dichotomous Test	Color Vision	Carbon Disulfide	Viscose Rayon Mfg.	
15. "	Color Vision	Multiple Chemicals	Pesticide Mfg.	
16. Pattern Comparison	Pattern Discrimination	Inorganic Lead	Storage Battery Mfg.	

Appendix 3 SENSORY TESTS

Test	Focus of Test	Chemical	Product, Industry, or Work Group	Reported Effect
17. Kuhnburg Figure Matching Test	Pattern Discrimination	Styrene	Polyester Plastics	
18. Benton Visual Retention Test	Pattern Discrimination	Carbon Disulfide	Viscose Rayon Mfg.	Yes
19. "	Pattern Discrimination	Solvent Mixtures	Auto Painting	
20. "	Pattern Discrimination	Inorganic Lead	Storage Battery Mfg.	
21. Benton Visual Reproduction Test	Pattern Discrimination	Solvent Mixtures	Auto Painting	
22. Benton Facial Recognition Test	Pattern Discrimination	Polybrominated Biphenyls	Farmers	
23. Letter Recognition	Pattern Discrimination	Carbon Monoxide	Toll Booth Operators	
24. Embedded Figures	Pattern Discrimination	Polybrominated Biphenyls	Dairy Farms	Yes
25. "	Pattern Discrimination	Inorganic Lead	Smelter Workers	Yes
26. Niesser Letter Search	Pattern Discrimination/ Vigilance	Carbon Disulfide	Viscose Rayon Mfg.	Yes
27. "	Pattern Discrimination/ Vigilance	Perchloroethylene	Dry Cleaners	
28. "	Pattern Discrimination/ Vigilance	Multiple Chemicals	Pesticide Mfg.	
29. Bourdon Wiersma	Numerosity/Vigilance	Carbon Disulfide	Viscose Rayon Mfg.	Yes

Appendix 3 SENSORY TESTS

Test	Focus of Test	Chemical	Product, Industry, or Work Group	Reported Effect
30. Bourdon Wiersma	Numerosity/Vigilance	Styrene	Polyester Plastics	Yes
31. "	Numerosity/Vigilance	Carbon Disulfide	Viscose Rayon Mfg.	Yes
32. "	Numerosity/Vigilance	Inorganic Lead	Storage Battery Mfg.	
33. Light Flash Monitoring	Vigilance	Inorganic Lead	Storage Battery Mfg.	
34. "	Vigilance	Methyl Chloride	Foam Products Mfg.	Yes
35. Audiometer	Pure Tone Thresholds	Inorganic Lead	Storage Battery Mfg.	
36. "	Pure Tone Thresholds	Inorganic Lead	Storage Battery Mfg.	Yes
37. Tone Decay Time	Pure Tone Thresholds	Inorganic Lead	Storage Battery Mfg.	Yes
38. Unstated	Finger Agnosia	Polybrominated Biphenyls	Farmers	
39. Unstated	Grapesthesia	Polybrominated Biphenyls	Farmers	
40. Unnamed	Finger Proprioception/ Steadiness	Organophosphates	Farmers, Applicators	

Appendix 4 MOTOR TESTS

Test	Focus of Test	Chemical	Product, Industry, or Work Group	Reported Effect
1. Grip	Strength	Polybrominated Biphenyls	Farmers	
2. Dynamometer	Strength	Inorganic Lead	Storage Battery Mfg.	
3. "	Strength	Inorganic Lead	Smelter Workers	
4. "	Strength	Mercury Chloride	Foam Products Mfg.	Yes
5. "	Strength	Inorganic Lead	Storage Battery Mfg.	
6. Finger Tremor	Steadiness	Inorganic Mercury	Glass Etching	Yes
7. Finger Tremor	Steadiness	Methyl Chloride	Foam Products Mfg.	Yes
8. "	Steadiness	Inorganic Lead	Storage Battery Mfg.	
9. Arm Tremor	Steadiness	Inorganic Mercury	Chloralkalai Mfg., Magnetic Materials	Yes
10. SAM Arm-Hand Tremor	Steadiness	Inorganic Lead	Storage Battery Mfg.	Yes
11. Rail Balancing	Equilibrium	Methyl Chloride	Foam Products Mfg.	Yes
12. Blind Toe Pointing Accuracy	Coordination	Inorganic Mercury	Chloralkalai Mfg., Magnetic Materials	
13. Symmetry Drawing	Coordination	Carbon Disulfide	Viscose Rayon Mfg.	
14. "	Coordination	Styrene	Polyester Products	Yes

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Appendix 4 MOTOR TESTS

Test	Focus of Test	Chemical	Product, Industry, or Work Group	Reported Effect
15. Mira Test	Coordination	Carbon Disulfide	Viscose Rayon Mfg.	Yes
16. "	Coordination	Styrene	Polyester Plastics	
17. "	Coordination	Solvent Mixtures	Auto Painting	Yes
18. "	Coordination	Carbon Disulfide	Viscose Rayon Mfg.	Yes
19. Pencil Flipping	Speed/Coordination	Inorganic Mercury	Chloralkalai Mfg., Magnetic Materials	
20. Toe Tapping Speed	Speed/Coordination	Inorganic Mercury	Chloralkalai Mfg., Magnetic Materials	Yes
21. Finger Tapping	Speed/Coordination	Inorganic Mercury	Chloralkalai Mfg., Magnetic Materials	Yes
22. "	Speed/Coordination	Solvent Mixtures	Auto Painting	Yes
23. "	Speed/Coordination	Polybrominated Biphenyls	Farmers	
24. Grooved Pegboard	Speed/Coordination	Polybrominated Biphenyls	Farmers	
25. Simple Reaction Time	Speed/Coordination	Inorganic Mercury	Chloralkalai Mfg., Magnetic Materials	
26. "	Speed/Coordination	Carbon Disulfide	Viscose Rayon Mfg.	Yes
27. "	Speed/Coordination	Styrene	Polyester Plastics	
28. "	Speed/Coordination	Solvent Mixtures	Auto Painting	

Appendix 4 MOTOR TESTS

	Test	Focus of Test	Chemical	Product, Industry, or Work Group	Reported Effect
29.	"	Speed/Coordination	Inorganic Lead	Smelter Workers	Yes
30.	"	Speed/Coordination	Perchloroethylene	Dry Cleaners	
31.	"	Speed/Coordination	Inorganic Lead	Smelter Workers	
32.	"	Speed/Coordination	Inorganic Lead	Storage Battery Mfg.	
33.	Santa Ana Dexterity	Speed/Coordination	Carbon Disulfide	Viscose Rayon Mfg.	Yes
34.	"	Speed/Coordination	Styrene	Polyester Plastics	
35.	"	Speed/Coordination	Solvent Mixtures	Auto Painting	Yes
36.	"	Speed/Coordination	Carbon Disulfide	Viscose Rayon Mfg.	Yes
37.	"	Speed/Coordination	Perchloroethylene	Dry Cleaners	
38.	"	Speed/Coordination	Carbon Disulfide	Viscose Rayon Mfg.	Yes
39.	"	Speed/Coordination	Inorganic Lead	Smelter Workers	
40.	"	Speed/Coordination	Inorganic Lead	Smelter Workers	Yes
41.	"	Speed/Coordination	Multiple Chemicals	Pesticide Mfg.	Yes
42.	"	Speed/Coordination	Inorganic Lead	Smelter Workers	Yes
43.	Michigan Eye-Hand Coordination Test	Speed/Coordination	Inorganic Mercury	Chloralkalai Mfg., Magnetic Materials	Yes
44.	"	Speed/Coordination	Carbon Monoxide	Toll Booth Collectors	Yes

Appendix 4 MOTOR TESTS

	Test	Focus of Test	Chemical	Product, Industry, or Work Group	Reported Effect
45.	"	Speed/Coordination	Inorganic Lead	Storage Battery Mfg.	Yes
46.	"	Speed/Coordination	Methyl Chloride	Foam Products Mfg.	
47.	"	Speed/Coordination	Inorganic Lead	Storage Battery Mfg.	
48.	"	Speed/Coordination	Inorganic Lead	Smelter Workers	
49.	Choice Reaction Time	Speed/Coordination/Decision	Inorganic Mercury	Chloralkalai Mfg., Magnetic Materials	
50.	"	Speed/Coordination/Decision	Carbon Monoxide	Toll Booth Collectors	
51.	"	Speed/Coordination/Decision	Styrene	Polyester Plastics	
52.	"	Speed/Coordination/Decision	Solvent Mixtures	Auto Painting	
53.	"	Speed/Coordination/Decision	Methyl Chloride	Foam Products Mfg.	Yes
54.	"	Speed/Coordination/Decision	Carbon Disulfide	Viscose Rayon Mfg.	Yes
55.	"	Speed/Coordination/Decision	Perchloroethylene	Dry Cleaners	
56.	"	Speed/Coordination/Decision	Inorganic Lead	Smelter Workers	
57.	"	Speed/Coordination/Decision	Multiple Chemicals	Pesticide Mfg.	Yes
58.	"	Speed/Coordination/Decision	Inorganic Lead	Smelter Workers	Yes

Appendix 5 TESTS OF COMPLEX FUNCTION/MEMORY

Test	Focus of Test	Chemical	Product, Industry, or Work Group	Reported Effect
1. Time Estimation	Time/Body Relationships	Carbon Monoxide	Toll Booth Collectors	
2. Dual Task	Tapping/Vigilance	Carbon Monoxide	Toll Booth Collectors	Yes
3. Dual Attention	Tracking/Peripheral Flash Detection	Formaldehyde	Plywood Mfg.	
4. Mental Arithmetic	Calculations	Carbon Monoxide	Toll Booth Collectors	
5. Mental Arithmetic	Calculations	Inorganic Lead	Storage Battery Mfg.	
6. "	Calculations	Methyl Chloride	Foam Products Mfg.	Yes
7. Digit-Symbol (WAIS)	Coding	Carbon Disulfide	Viscose Rayon Mfg.	
8. "	Coding	Perchloroethylene	Dry Cleaners	
9. "	Coding	Polybrominated Biphenyls	Dairy Farmers	
10. "	Coding	Inorganic Lead	Smelter Workers	Yes
11. "	Coding	Multiple Chemicals	Pesticide Mfg.	
12. Block Design (WAIS)	Spatial Relations	Carbon Disulfide	Viscose Rayon Mfg.	Yes
13. "	Spatial Relations	Multiple Chemicals	Pesticide Mfg.	Yes
14. "	Spatial Relations	Polybrominated Biphenyls	Dairy Farmers	
15. "	Spatial Relations	Inorganic Lead	Storage Battery Mfg.	Yes

Appendix 5 TESTS OF COMPLEX FUNCTION/MEMORY

Test	Focus of Test	Chemical	Product, Industry, or Work Group	Reported Effect
16. WAIS (4 subtests)	Intelligence	Solvent Mixtures	Auto Painting	Yes
17. WAIS (5 subtests)	Intelligence	Carbon Disulfide	Viscose Rayon Mfg.	Yes
18. "	Intelligence	Styrene	Polyester Plastics	
19. WAIS	Intelligence	Polybrominated Biphenyls	Farmers	
20. Raven Progressive Matrices	Intelligence	Multiple Chemicals	Pesticide Mfg.	
21. Multilingual Aphasia Exam	Memory	Organophosphates	Farmers, Applicators	
22. Digit Span (WAIS)	Memory	Carbon Disulfide	Viscose Rayon Mfg.	
23. "	Memory	Perchloroethylene	Dry Cleaners	
24. "	Memory	Multiple Chemicals	Pesticide Mfg.	
25. Wechsler Memory Scale	Memory	Styrene	Polyester Plastics	
26. "	Memory	Solvent Mixtures	Auto Painting	Yes
27. "	Memory	Polybrominated Biphenyls	Farmers	Yes
28. "	Memory	Inorganic Lead	Storage Battery Mfg.	Yes
29. Trigram Recall	Memory/Distraction	Organophosphates	Farmers, Applicators	
30. Memory Distractor Test	Memory/Distraction	Polybrominated Biphenyls	Farmers	

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8. Performing Organization Rept. No:

9. Performing Organization Name and Address

Rocky Mountain Center for Occupational and Environmental Health, University of Utah

10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.

(C)

(G)

12. Sponsoring Organization Name and Address

13. Type of Report & Period Covered

14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

A walk through survey and a followup on/site environmental and medical evaluation of potentially exposed workers were carried out at Hill Air Force Base (SIC-9711), Ogden, Utah. Followup on/site environmental and medical evaluations of potentially exposed workers were conducted at Koldaire, Inc., Salt Lake City, Utah. Past medical records at Hill Air Force Base and historical worker exposure information were deemed adequate to onstruct probable exposures to hazardous materials during the performance of various k assignments at the base and to permit a morbidity study to be conducted. Research at base was investigated. Major chemicals used at the base were listed. Human health ...ects and toxicology of organic solvents and chemicals were reviewed. Studies at Koldaire, Inc., located in Salt Lake City, Utah, were prompted by a former employee who developed progressive neurologic illness which he attributed to exposures he encountered as a refrigeration serviceman. Possible exposures in this area of work include fluorocarbons, phosgene (75445), hydrogen-chloride (7647010), hydrogen-fluoride (7664393), welding fumes and cadmium (7440439). The investigation indicated his peripheral nerve disease was probably not related to hazardous exposures during his work. It was recommended that respirators be worn by refrigeration repairmen, that medical surveillance be performed yearly, and that eye protection be worn during welding and soldering operations.

17. Document Analysis a. Descriptors

b. Identifiers/Open-Ended Terms

NIOSH-Publication, HHE-81-458, HHE-81-043, NIOSH-Grant, Grant-Number-OH-01249-01, Cleaning-compounds, Solvent-vapor-degreasing, Organic-solvents, Military-personnel, Morbidity-rates, Neuropathology, Respiratory-system-disorders, Radiation-exposure, Welders

c. COSATI Field/Group

vailability Statement

19. Security Class (This Report)	21. No. of Pages 181
20. Security Class (This Page)	22. Price

(See ANSI-Z39.18)

See Instructions on Reverse

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