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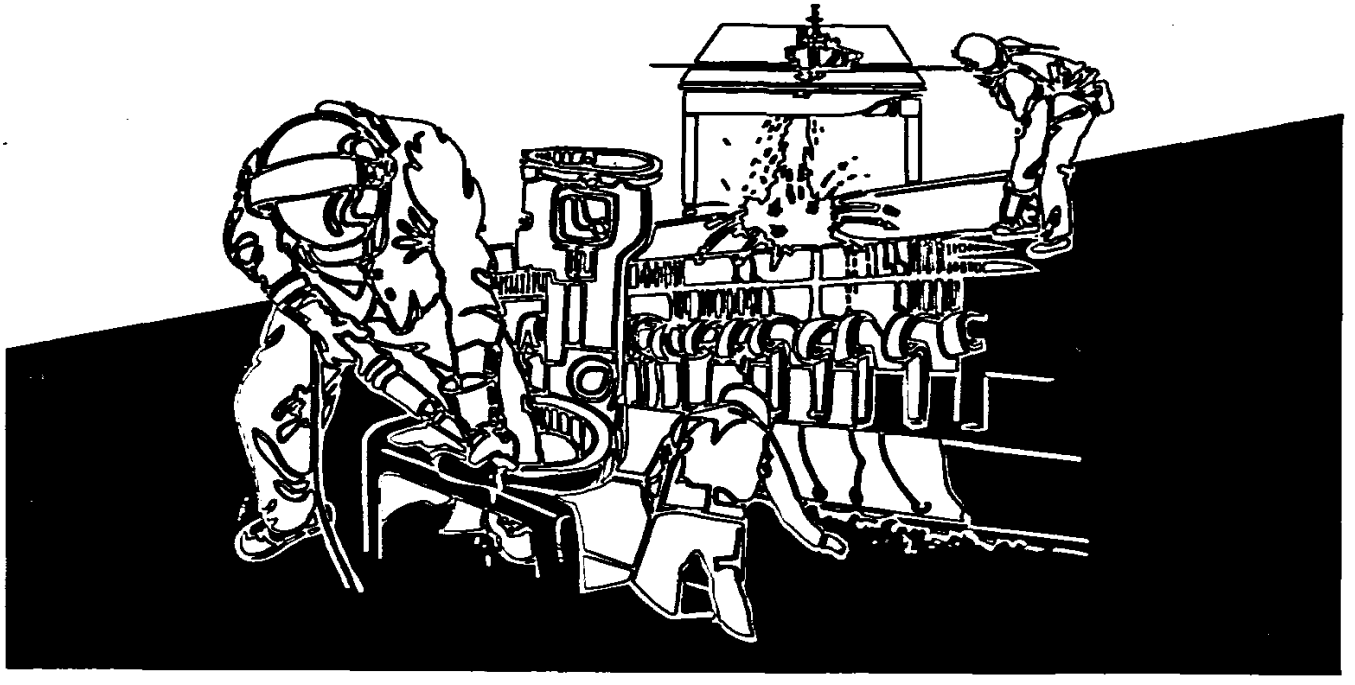
CDC
CENTERS FOR DISEASE CONTROL AND PREVENTION

NIOSH HEALTH HAZARD EVALUATION REPORT

HETA 90-0149-2522
INTALCO ALUMINUM CORPORATION
FERNDALE, WASHINGTON



U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Public Health Service
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

PREFACE

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

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

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AUGUST 1995
INTALCO ALUMINUM CORPORATION
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SUMMARY

In February 1990, the National Institute for Occupational Safety and Health (NIOSH) received a request for a Health Hazard Evaluation (HHE) from three employees at the Intalco aluminum reduction plant in Ferndale, Washington. The request concerned the development among aluminium potroom workers of a progressive neurological condition characterized by tremor, balance problems, bone and joint aches, and memory loss.

In November 1993, NIOSH investigators conducted a cross-sectional study of 63 current and former aluminum potroom workers first employed prior to 1970, to determine the prevalence of neurological disorders consistent with previous reports. A group of 37 cast house and carbon plant workers with similar lengths of employment and starting dates in the plant was used as a comparison group. Data collection included a questionnaire, neurologic exam, tremor testing using a hand held device (arm/hand) and a Kondraske frame (leg), and tests of postural stability, reaction time, and vocabulary.

No significant differences in age, racial origin or education level were found between the two groups. While the potroom group had higher prevalences for most of the neurologic symptoms, the only symptom for which a statistically significant higher prevalence was found was incoordination. For two of the symptoms, difficulty buttoning and depression, the higher prevalences in the potroom group were of borderline statistical significance. Tests of arm/hand and leg tremor in both the visible (1-6 hz) and part of the non-visible (7-12 hz) frequencies did not show any statistically significant differences between the two groups. Testing of postural stability found no definitive pattern of neurologically meaningful differences between the groups. There were no differences in reaction time, vocabulary score, and findings on clinical neurologic assessment between the two groups.

There were several limitations to this study, however, and the results should be interpreted with caution. First, the cross-sectional study design makes it difficult to identify temporal relationships between risk factors and medical conditions, such as neurologic disorders, which may take many years to develop. Second, the low participation rate of former workers may mean that former workers who had developed neurologic problems could not (or chose not to) participate in the study. Finally, the potroom group may have been more likely to report symptoms than the comparison group because they were more aware of job-related stressors as several prior studies had been conducted on this same group.

On the basis of this evaluation, objective measures of neurologic function did not support the finding of increased neurologic symptom prevalences and NIOSH investigators concluded that there were no objective differences in neurologic function between the potroom and comparison workers tested at Intalco. The results of this investigation provide no basis for concluding that neurologic effects among potroom workers at Intalco are related to the working environment in the potrooms.

KEYWORDS: SIC 3334 (Aluminum processing) aluminum, neurologic function, potroom workers, tremor, incoordination, reaction time, vocabulary.

INTRODUCTION

In February 1990, the National Institute for Occupational Safety and Health (NIOSH) received a request for a Health Hazard Evaluation (HHE) from three employees at the Intalco Aluminum reduction plant in Ferndale, Washington. The request concerned the development of a progressive neurological disease characterized by tremor, balance problems, bone and joint aches and memory loss among aluminum potroom workers (Longstreth et al, 1985). There was a particular concern regarding exposures occurring prior to 1972, before aluminum reduction pot containment hoods were installed at the plant. NIOSH was requested to investigate the nature of the neurologic problems and identify possible occupational causes.

In response to this request, NIOSH investigators met with representatives of management and unions on several occasions at the plant in Ferndale. During 1991 and 1992, site visits were conducted to undertake walk-through surveys of the plant, to extract information from personnel files about potential participants in the HHE, and to review previously collected industrial hygiene monitoring data.

In November 1993, NIOSH investigators conducted a field study involving examinations of 100 current and former workers at the Ferndale plant.

BACKGROUND

Process Description

The aluminum reduction plant at Ferndale commenced operation in 1966. Intalco utilizes the side-break, pre-bake Hall-Heroult process to reduce alumina into aluminum. This process is described below. There has been little change to the production methods or raw materials used by Intalco since production began. However, the pots were not enclosed from 1966 until 1972, when hoods were added.

Aluminum production is a three step process:

1. bauxite, which has a high aluminum content, is mined;
2. aluminum oxide, known as alumina, is chemically extracted from bauxite; and
3. alumina is reduced by electrolysis to produce pure aluminum.

For the Intalco plant in Ferndale, Washington, steps 1 and 2 are carried out in Australia. The alumina is transported to the Ferndale plant, where the third step, using the Hall-Heroult electrolytic process, is carried out. In this process, alumina, which has a melting point of 2000° C, is dissolved in a molten cryolite bath. Cryolite is a fluorinated compound of sodium and aluminum with a melting point of 1000°C. In its molten state, cryolite can dissolve 8% of

alumina. Other bath components include fluorospar and aluminum fluoride. The alumina, dissolved in the cryolite bath, is then subjected to electrolysis, which separates the alumina into pure aluminum and oxygen. The dense molten aluminum settles to the bottom of the cryolite bath and is removed by siphoning.

The electrolytic cell is termed a pot, a series of electrically connected pots is a potline, and the building which houses the potlines is known as a potroom. The Hall-Heroult electrolytic process utilizes anodes and cathodes composed of carbon and coal tar pitch. As electrolysis proceeds, oxygen, freed by the reduction process, combines with carbon from the anode to form carbon dioxide. During the electrolytic process, the anode is consumed.

During alumina reduction a crust forms on top of the bath. The crust must be broken to feed more alumina into the pot. Center-break or side-break methods are used in pots with pre-baked anodes. Crust in center-break pots may be broken without opening the fume collection hoods, and alumina can be fed continuously. In side-break pots, such as those used by Intalco, the fume hoods must be lifted to reach and break the crust. Mechanization may decrease dust exposure with side-break pots, but dust and fume exposures in side-break potrooms are generally higher than in center-break potrooms (Shuler and Bierbaum 1974).

Anodes are supplied in one of two ways in aluminum reduction plants. In the method utilized by Intalco, pre-baked anodes are manufactured in the carbon plant at the site. In this process the anodes are pre-formed from carbon and coal tar pitch, then baked and hardened before being placed in the pots. In the pre-bake method, the volatilization of coal tar pitch in the potroom is less than that produced using the Soderberg anode method (Shuler and Bierbaum 1974). The Soderberg method has not been used at the Ferndale plant.

Molten aluminum is siphoned from the pots and transferred by ladles to the casting area. The aluminum is maintained in a molten state while various materials are added to create the desired alloys. The metal is then poured into molds and water-cooled.

Previous Studies of Intalco Workers

The possible link between work in the potrooms at the Intalco plant and neurologic problems was first raised in a published article by Longstreth et al (1985), who reported a case series of three Intalco aluminum potroom workers who presented with incoordination and intention tremor. This condition was labelled 'potroom palsy.' Two of the three workers were also diagnosed as having cognitive deficits. The cause of these neurologic disorders was unknown, but the authors hypothesized that the neurologic deficits were related to exposures, most likely to aluminum, in the potroom at the Intalco plant at Ferndale.

Following publication of the Longstreth et al article, several other Intalco workers sought medical attention for neurologic problems, and many of these workers subsequently filed worker's compensation claims for neurologic disability. These workers included the three described by Longstreth et al (1985). Most of the workers who submitted claims had begun work in the plant in either 1966 or 1967 and worked in the vicinity of the potlines prior to the installation of ventilation hoods in 1972. Symptoms reported by these workers included imbalance/ataxic gait, difficulty with memory and concentration, tremor, headache, muscle and joint aches, numbness/parathesias, chronic fatigue, and depression.

Following the submission of these workers' compensation claims, Intalco commissioned a consultant research group to conduct an investigation into neurologic disorders among workers in the Ferndale plant. This investigation was conducted between May 1988 and July 1989, and an unpublished report was released in October 1989. The aims of this study were to determine whether sufficient medical and neurologic data existed to derive a consistent diagnosis of observed neurologic health effects in the Intalco workers, and to test for associations between central nervous system symptoms and occupational chemical exposures at the Intalco plant.

The medical part of the consultant's investigation was conducted in two phases. The first phase was a clinical and neurologic case review of the medical records of the nine central nervous system disability claimants at the time of the study. The clinical case review found that three of the nine claimants had clear neurologic disease, but that the three conditions appeared unrelated to each other. It also found that the other six claimants had no evidence of a recognised neurologic disease. The neuropsychologic case review found evidence for central nervous system dysfunction in four cases and borderline dysfunction in one further case. This study concluded that it was unlikely known workplace exposures could account for the range of neuropsychologic symptoms reported by the claimants.

The second phase of the consultant's investigation comprised a study of 139 workers from the potlines (48 workers), carbon plant (42 workers), and cast house (49 workers). To be included in this part of the investigation, workers must have started work prior to 1977, worked at the Intalco plant for at least 10 years, and spent at least 75% of their work time in one of the three major employment divisions of the plant (potroom, carbon plant, or cast house). A retrospective study was conducted using symptom questionnaire data previously collected by mandatory periodic health exams of these workers during their employment at the Ferndale plant. In addition, a cross-sectional symptom prevalence study was carried out on 104 of the 139 workers who took part in the retrospective study. Retired workers were excluded from this cross-sectional study. Historical industrial hygiene records, as well as air monitoring data collected in 1989, were used to provide exposure parameters.

The consultant's study found a small positive dose-response relationship between central nervous system symptoms and cumulative exposure to measured air levels of particulates. However, the magnitude of the increased symptom reporting was small across the three exposure subgroups,

and no consistent pattern of symptom reporting was found. The dose-response relationship was strongest for impaired concentration, impaired memory, imbalance, incoordination and headache. No dose-response relationship was found for tremor.

Despite the above findings, the consultants concluded that there was no specific neurotoxic effect found in the potline workers. As aluminum was the contaminant found in highest concentration in the air-borne particulate in the potrooms, the consultants suggested that the increased neurologic symptom reporting in the potroom workers may be related to higher exposure to aluminum.

In 1990, Intalco retained an occupational physician to head a clinical investigative panel to examine and/or review the medical records of the 11 workers who had made a compensation claim. These 11 claimants had all worked in the potroom and included the nine claimants already reviewed in the consultant's study described above. The occupational physician concluded that one worker had probable multiple sclerosis, two had probable myelopathy, one had cervical spondylosis with myelopathy, two had signs suggestive of a multi-system neurologic illness, and one had non-specific signs which were not compatible with any known neurologic disorder. This investigation did not identify any occupational cause for the neurological disorders in these workers. The occupational physician found little or no evidence of a neurological disorder in any of the remaining four workers.

Since 1990, additional Intalco workers have filed compensation claims. These claimants, through their legal counsel, retained a consultant to undertake an epidemiological study of Intalco workers. The consultant conducted a cross-sectional symptom prevalence survey of current and former Intalco workers. Telephone interviews were conducted with 964 (72%) of the 1331 workers who had worked for at least 10 years at the Ferndale plant. For the purpose of the study, the operational definition of a 'case' was a worker who reported eight or more neurologic symptoms occurring at least daily.

Comparing cases with non-cases, an odds ratio (adjusted for age) of 4.6 was found for workers who had worked for at least three years in the potrooms prior to 1974. When the same analysis was conducted after the 26 workers who had filed disability claims for neurologic disorder were excluded from the analysis, the adjusted odds ratio was 2.3. This result was not statistically significant.

Associations were also found between at least three years of work in the potroom prior to 1974 and the following individual symptoms; incoordination (adjusted OR=1.9), tremor (adjusted OR=2.0), loss of strength (adjusted OR=1.9) and frequent loss of balance (adjusted OR=1.8). All were statistically significant at the 0.01 level. When this analysis was repeated without the 26 claimants, the odds ratios were still elevated (range=1.4-1.5), but incoordination and tremor

were the only two symptoms where the p-value was less than 0.05. A further analysis of potroom workers employed only after 1974 failed to find any association between work in potrooms and neurologic symptoms.

A further case series report of 25 Intalco workers from the Ferndale plant has recently been published (White et al, 1992). This group of 25 workers included the three workers described in the original case series of Longstreth et al (1985). The most frequently reported symptoms were frequent loss of balance (88%), memory loss (84%), joint pain (84%), dizziness (80%), numbness (80%) and severe weakness (80%). Neurological evaluation found that the most common findings related to incoordination. These included tremor, dyssynergy of upper limb movements, and ataxia, one or more of which were present in 84% of the 25 patients.

Neuropsychological evaluation of these 25 patients found that most had impaired memory functioning, abstract reasoning, flexible thinking and sustained attention. Most cases were suffering from depression at the time of the study. This was found on both clinical evaluation and testing with the Minnesota Multiphasic Personality Inventory. With the exception of frequent loss of balance, no symptoms or signs were associated with work in the potroom prior to 1972.

Apart from the studies of Intalco workers there have only been two published studies which investigated the relationship between neurologic disorders and employment in an aluminum smelter. Langauer-Lewowicka and Braszczynska (1983) found a 9% prevalence of neurologic problems in 444 aluminum electrolysis workers. Since the completion of field work for the Intalco HHE, the results of another cross-sectional study of neuropsychological deficit in 38 workers in a Norwegian primary aluminum plant have been published (Bast-Pettersen et al, 1994). This study found that potroom and foundry workers were more likely to have reported three or more neuropsychiatric symptoms than the workers in the comparison group. Tests of motor function found evidence of a subclinical tremor in the potroom group, and tests of cognitive function showed a statistically significant unstable tendency towards impaired visuospatial organization in this group. No differences were found between the groups with respect to reaction time, memory, or motoric/sensoric tempo.

In summary, three case series and two epidemiologic studies of Intalco employees have reported neurologic effects among potroom workers, particularly for those employed prior to the installation of hoods on the potline in 1972. The most consistent physical signs and abnormalities on neurobehavioral testing of the workers in the case series have been related to incoordination, tremor, and memory loss. The two epidemiologic studies have investigated only symptom reporting (ie, not physical signs or neurobehavioral tests) and have confined their study groups to current workers. The two published studies of workers employed in other aluminum plants have found evidence for increased prevalence of neuropsychiatric symptoms and, in one study, evidence for increased tremor and cognitive dysfunction, among long-term potroom

workers. In each of these studies, aluminum exposure has been suggested as the likely cause of any neuropsychologic disorders. The role of aluminum as a possible neurotoxin is discussed further in the Evaluation Criteria section.

METHODS AND MATERIALS

Industrial Hygiene

Company industrial hygiene air monitoring data was reviewed. Air sampling data dates back to 1968 and has been performed for total particulates, fluorides, coal tar pitch volatiles, carbon monoxide and sulfur dioxide. No aluminum air monitoring data has been collected by Intalco. The results of the consultant's air monitoring data for respirable aluminum conducted in 1988 were also reviewed to help estimate aluminum exposures for the groups included in the HHE. No new industrial hygiene monitoring was done as part of this HHE because of the retrospective nature of the investigation and the prime interest relating to exposures up to 25 years ago.

To aid in defining groups to be included in the investigation, work history data, such as date commenced in the plant, time spent working in the plant, job departments, and job titles, were extracted from personnel records. This is discussed further in the next section.

Medical

The primary medical objectives of the HHE were to test the following hypotheses:

1. That the prevalence of neurologic symptoms reported by potroom workers at the Intalco plant is higher than that of Intalco workers employed outside the potrooms.

2. That the prevalence of abnormal neurologic examination findings, particularly tremor and incoordination, is higher in potroom workers at the Intalco plant than in Intalco workers employed outside the potrooms.

3. That Intalco potroom workers have significantly more tremor and incoordination (assessed by objective testing), poorer vocabulary, and slower reaction time than Intalco workers employed outside the potrooms.

This cross-sectional study included both current workers and former workers. The inclusion of former workers was an important feature of this study because of a potential survivor bias if only current workers were studied. The presence of neurologic disorders was assessed using four methods; neurologic symptom questionnaire, neurologic examination, neurobehavioral tests, and objective tests of tremor and postural stability.

Two groups of participants were selected, one comprising potroom workers, and a comparison group comprising cast house and carbon plant workers. The two groups were selected using several eligibility criteria, which were set to maximize differences in aluminum exposure between the two groups. These criteria were based on the work histories of the neurologic cases previously reported, industrial hygiene records and the timing of the installation of hoods in the potroom. The two groups comprised workers with similar employment histories with Intalco, apart from location of work within the plant. This helped to minimize differences between the two groups with respect to demographic and other employment factors, which may act as confounding variables. The eligibility criteria for each group were:

Potroom Group

1. At least two years of employment in the potroom prior to January 1, 1972 (i.e., prior to ventilation hoods being placed on pots), and

2. At least ten years of work in the potroom at Intalco.

Carbon Plant/Cast House Group

1. At least two years of employment in the cast house or carbon plant prior to January 1, 1972,

2. At least ten years of work in the cast house and/or carbon plant at Intalco, and

3. No periods of work in the potroom.

Apart from workers in the potroom, cast house and carbon plant, the other two large worker groups in the plant are administrative and maintenance workers. We decided not to include these workers in the comparison group because of likely differences in factors such as socioeconomic status (administrative workers) and potential for mixed exposure (maintenance workers).

Workers who met the criteria for inclusion in the two study groups were selected using work histories in personnel files. These data were obtained in 1992 and included: badge number(s), social security number, date of hire, date of termination, and dates and title of all jobs held at Intalco. In total, 98 potroom workers (65 still employed and 33 former workers) and 76 comparison workers (49 still employed and 27 former workers) met the eligibility criteria for their group:

Former workers who met the above eligibility criteria were sent a letter to their last known address asking them to take part in the study. This letter included details of the testing required of each participant in the study. All selected former workers were asked to return a card which indicated whether they wished to take part. Those who indicated that they wished to participate were contacted by telephone to make a date and time for attendance at the plant.

Current workers who met the above eligibility criteria were given a similar letter in their pay packet just prior to the start of the study. This letter outlined the testing procedures and advised the workers that they would be asked to come off the production line during the study period to read the consent form and decide whether they wished to participate.

Current and former workers who met the eligibility criteria for the study were invited to participate on a strictly voluntary basis. A careful explanation of the right to refuse participation and of the Privacy Act (including conditions under which confidential information could be released) was given to each participant before any procedures were done or questionnaires administered.

Data collection took place in November 1993 at Intalco's Ferndale plant for both current and former Intalco workers. All participants were asked to complete a questionnaire, undergo a neurologic examination, and undergo several neurologic and neurobehavioral tests. Examiners were blinded to the exposure status of each participant. Details of the instruments used for data collection follow:

Questionnaire

The self-administered questionnaire contained detailed questions about the worker's symptoms, personal and family medical history, smoking pattern, caffeine and alcohol use, and work history before and after employment with Intalco. Although the questionnaire was self-administered, this was closely supervised by a NIOSH investigator who was available to answer any questions and who immediately checked completed questionnaires for missing data and discrepancies.

Physical Examination

A physical examination focusing on the nervous system was performed by a neurologist. A standardized data form was used to record the findings of this examination. The neurologic exam focused on signs of tremor, incoordination, and cognitive deficits. A mini mental state examination was also done by the neurologist. Where neurologic abnormalities were found, the neurologist took a relevant history to determine the presence of non-occupational causal factors.

Hand/Arm Tremor

Hand/arm tremor was measured using a device developed by NIOSH scientists that uses accelerometers mounted inside a T-shaped apparatus made of plastic pipe to measure dynamic aspects of the amplitude and frequency of hand movements (Galinsky et al 1990). A subject holds the device in the preferred hand and sights through the cross of the T at a circular patch on the wall. The device is fully automated and can take measurements continuously for up to ten minutes. Tremor in both the horizontal and vertical directions is measured and characterized.

The device is sensitive to physical fatigue effects, whereby tremor increases as the test progresses, and this factor may enhance the effect on tremor of any damage due to exposure (Galinsky et al., 1990). A three minute sample of tremor was chosen for the Intalco study to compare the potroom and comparison (carbon plant/cast house) groups and assess the effect of the following three variables: (1) exposure group (i.e., potroom vs comparison); (2) physical fatigue; and, (3) the interaction between fatigue and exposure group. The test was conducted in one hand only.

Leg Tremor

Leg tremor was assessed using an inductive field method (Kondraske 1986). This test device assesses the amplitude and frequency of leg/foot movements. Participants extend their preferred leg into an open picture frame type device which measures tremor by displacement. The measurement period used for this test was three minutes.

Standing Postural Stability

The postural stability test was conducted on a strain force-sensing platform (Dick et al. 1990). The platform senses the participant's center of mass 10 times per second over the 30 second time span of each test. Software developed by the manufacturer converts the 300 recorded center-of-mass positions into measures of the overall path length, path area, and mean radius of the polygon created by tracing the moving center of mass.

Each participant was tested 12 times, twice in each of the following six conditions:

1. Standing on the hard surface of the platform and visually fixating on an "x" located at eye level 10 ft. in front (HEO1 and HEO2).

2. Standing on the hard surface of the platform with both eyes closed (HEC1 and HEC2).

3. Standing on a 4-in. compliant foam pad with eyes open and fixating on the "x" (SEO1 and SEO2).

4. Standing on the foam pad with both eyes closed (SEC1 and SEC2).

5. Standing on the left leg while fixating on the "x" (LL1 and LL2).

6. Standing on the right leg while fixating on the "x" (RL1 and RL2).

After these 6 conditions were sampled, the participant was asked to repeat the sequence.

For tests 1-4 and 7-10, the participant was simply asked to stand on the platform with his hands comfortably falling by his sides, and to remain as motionless as possible for 30 seconds, beginning and ending with the test administrator's signal. For tests 5-6 and 11-12, the participant was instructed to stand as motionless as possible on the appropriate leg, but was allowed to use his arms to maintain his balance. The reason for the latter is that very few people can stand motionless on one leg after the first 15-20 seconds of the test.

The raw scores were expressed in inches for path length and mean radius, and in square inches for area.

Reaction Time

Reaction time is a test of visual-motor speed and processing. It was assessed by using a testing device comprising a console with a small indicator light and push-button. This device is a component of the WHO-NIOSH Neurobehavioral Core Test Battery and is a standard component of clinical and neurobehavioral assessment (World Health Organization, 1988). While seated at the console, each participant was asked to place the index finger of the preferred hand over the push-button and instructed to respond to the brief illumination of the light by pressing the button as quickly as possible. Within 1 to 10 seconds of the button response, the light again was presented. This procedure was repeated for 64 trials over a 6-minute period.

Vocabulary

Vocabulary testing was assessed using the revised Wechsler Adult Intelligence Scale (WAIS-R) vocabulary component (Wechsler, 1981). This test provides an index of verbal intelligence that is more stable over time than other measures of intelligence. Assessment of vocabulary was needed to compare with motor performance in the overall evaluation, as vocabulary is more resistant than motor performance to chemical insult and is therefore a better indicator of pre-exposure level of cognitive function.

Each participant was verbally and visually presented with a series of 35 words of increasing difficulty by a trained NIOSH investigator. The participant then told the meaning of each word to the examiner, who wrote the response on the WAIS record form. The examiner prompted the participant to provide more information if the initial response was vague. The test was discontinued after 5 consecutive failures (responses scored 0). Each response was given a score of 0, 1, or 2, according to 15 general scoring principles.

EVALUATION CRITERIA

Of the airborne chemical contaminants present in the potrooms, aluminum is the only one which is a documented neurotoxin in animal studies (Golub et al. 1989). In the previous reports and published papers related to the Intalco plant, aluminum has usually been suspected as a possible cause of excess neurologic disorders in potroom workers.

Aluminum can be absorbed into the body via inhalation and through the gastrointestinal tract, although absorption through the latter route is poor (Kaehny et al. 1977). Following absorption, aluminum is retained and stored in at least two functional compartments of the body and eliminated from these compartments at different rates (Sjogren et al. 1988). The half-life for removal from one compartment (comprising soft tissues) is a few hours to a few days, whereas elimination from the second compartment (probably comprising the skeleton and lungs) has a half-life of several months to years depending on the period of exposure. It has been shown that absorbed aluminum can be retained in the body of exposed workers for many years following the cessation of exposure (Elinder et al. 1991).

Aluminum is a well-accepted cause of dialysis encephalopathy in patients with renal failure (Wills and Savory 1985). The association of aluminum levels in brain tissue of patients with Alzheimer's disease remains controversial because it is unknown whether the accumulated aluminum is a cause or effect of the damaged neurons (Crapper 1986).

In 1962, an aluminum-exposed worker was reported to have pulmonary fibrosis, rapidly progressive encephalopathy and seizures. A post-mortem examination showed an elevated level of aluminum in both brain and lung tissue. A follow-up study of co-workers found no definite cases of aluminum-induced pulmonary fibrosis; no neurological testing was reported (McLaughlin et al. 1962).

In a recent study, the cognitive functioning of miners who were exposed to a finely ground aluminum powder (containing 85% aluminum oxide and 15% elemental aluminum) as a purported prophylaxis against silicotic lung disease was compared to the cognitive functioning of nonexposed miners. A greater proportion of the exposed miners were in the impaired range. In addition, the likelihood of scores in the impaired range increased with duration of exposure (Rifat et al. 1990).

In summary, there is some human evidence to support the hypothesis that aluminum exposure may be implicated as a cause of neurologic disorders found in aluminum potroom workers. The NIOSH RELs for aluminum are 10 mg/m^3 for total dust and 5 mg/m^3 for respirable dust. The OSHA permissable exposure limits (PEL) are 15 mg/m^3 for total dust and 5 mg/m^3 for respirable dust (category of dust not elsewhere classified). At the present time, the American Conference of Governmental Industrial Hygienists (ACGIH) has a threshold limit value (TLV) of 10 mg/m^3

time-weighted average for total aluminum dust, which is set on the basis of its property as a "nuisance" dust. The potential neurologic effects of aluminum were not taken into account by any of these organizations when setting these workplace exposure limits.

RESULTS

Industrial Hygiene

Worker exposures in aluminum potrooms include; alumina dust, aluminum fume and dust, fluoride and cryolite dust and fumes, lithium, coal tar pitch volatiles (CTPV), heat, noise, and magnetic fields. Industrial hygiene monitoring conducted by the company dates back to 1968. Samples have been collected for (in decreasing order of number of samples) total particulates (TP), fluorides (total, particulate, and gaseous fraction), CTPV, carbon monoxide (CO), and sulfur dioxide (SO_2). Since 1968, a total of 1788 personal and 224 areas samples have been collected at Intalco.

Most of the samples have been taken for total particulates (TP). Levels for TP varied considerably in each department over the years but were consistently higher in the potrooms than in the carbon plant, which were higher than in the cast house. Rough arithmetic means for these departments over the years 1968 to 1988 are:

Potrooms 12.5 mg/m^3,
Carbon plant 10.5 mg/m^3, and
Cast house 4.5 mg/m^3.

The actual range of respirable aluminum concentrations was wide, with 1128 (95%) of the samples falling in the range 0.00-48.94 mg/m^3.

In 1972, Intalco began to fit the pots with hoods and local exhaust systems. By 1973, all pots, except for a portion on potline A, had been hooded. A NIOSH survey in 1973 compared exposures at hooded and non-hooded potline areas (Larsen et al. 1973). Exposures to total particulate were 3-8 times greater at the non-hooded pot areas when compared to hooded pot areas. Exposures for benzene solubles, total and soluble fluorides, and CO were all higher near the non-hooded pots.

Samples collected for Intalco by the consultant in 1988 documented varied ratios of respirable to total particulates within departments and throughout the plant. They also documented the amount of aluminum exposure by respirable fraction by department and found that the carbon plant had about 2 times more exposure to respirable aluminum dust than the cast house, and the potrooms had about 6.3 times as much exposure than the cast house (e.g., if cast house exposure = 1, carbon plant = 1.9, and potroom = 6.3).

The consultant also found that 19-34% of the total particulate was respirable, and of the respirable fraction, 70-94% was aluminum. Assuming that the fractional breakdown of dust in 1989 accurately reflects the fractional breakdown of dust prior to 1989, then the mean of respirable dust prior to 1989 is between 2.37 and 4.24 mg/m^3. Similarly, the mean respirable aluminum can be estimated to be between 1.66 and 3.99 mg/m^3. These calculations, however, are based on a single summary number (12.48 mg/m^3) representing the mean total particulate of 1186 samples, with a wide standard deviation (18.23 mg/m^3).

Total fluoride exposure has been high in the carbon plant and in the potrooms. Gaseous fluoride exposure has been highest in the potrooms. CTPV exposure has been highest in the carbon plant, particularly in the years 1968-72. Exposures to CTPV in the potrooms has been moderate to low. Moderate to low exposures to SO_2 and CO have been documented in the potrooms.

Quality of the industrial hygiene data is reasonable given the years in which they were generated. While the methods used varied over time, it is fair to assume that the trends and the relative exposures established by the data are valid. The reason the samples were collected also varied, from compliance monitoring to process change monitoring. The specifics of the data may have had less validity in earlier years.

In summary, potroom workers were exposed to higher levels of total particulates and to respirable aluminum particulates than workers in the carbon plant and in the cast house. CTPV exposures were highest in the carbon plant, followed by the potroom, with negligible exposure in the cast house. Total fluoride exposures generally were comparable in potrooms and the carbon plant, while hydrogen fluoride levels were highest in the potrooms. Fluoride levels in the cast house were low. C0 and $S0_2$ levels were highest in the potrooms and negligible elsewhere.

Medical

The medical part of the investigation was conducted over six days in November, 1993 at the Intalco Ferndale plant. Of the 65 potroom workers still employed in the plant who met the eligibility criteria, 52 took part in the study (80%). Of the 33 former potroom workers who met the eligibility criteria, 11 took part (33%). Of the 49 comparison workers still employed in the plant who met the eligibility criteria, 35 took part in the study (71%). Of the 27 former comparison workers who met the eligibility criteria, 2 took part (7%). A total of 100 workers (63 potroom workers and 37 comparison workers) took part in the study. Four of the potroom group had put in previous compensation claims for neurologic disorders.

Because of the low participation rates for former workers in both the study and comparison groups, and the small number of compensation claimants, the following analyses were usually repeated with former workers and compensation claimants excluded.

The demographic characteristics of the two groups are summarized in Table 1. There were no statistically significant differences between the potroom and comparison workers with respect to age, race, or education level. The analysis was repeated with the former workers excluded, and again, no statistically significant differences were found for these three demographic variables.

Neurologic symptoms

Odds ratios with 95% confidence intervals were calculated for neurologic symptoms reported on the self-administered questionnaire. The four frequency categories for each symptom (not at all, a little, moderately, and quite a lot) were dichotomized by collapsing them into two categories for calculation of the odds ratios. As several of these dichotomised symptoms had expected counts less than five, StatXact was used to obtain confidence intervals and p-values for these odds ratios.

The results of these analyses are outlined in Table 2. For all of these symptoms, except weight loss, the point estimates for the odds ratios were elevated, ranging from 1.57 for memory loss to 10.59 for incoordination. Because of the small numbers in the groups, the confidence intervals for these odds ratios were very wide, with three lower limits at the 95% level above unity (for incoordination, depression and difficulty buttoning clothes). The results for depression and difficulty buttoning were of borderline statistical significance.

When the analyses were repeated with former workers and the four compensation claimants excluded from the analysis, the odds ratios for depression and difficulty buttoning were lower and no longer statistically significant.

Neurologic signs

The general level of alertness was assessed by the neurologist as normal for all participants in each group. The general mental state of each participant was assessed by the neurologist as follows: four (6%) of the potroom group were classified as 'tense,' while two (5%) of the comparison group were classified as 'tense,' one potroom worker (3%) was 'agitated,' and one potroom worker (3%) was 'depressed.' The rest of the participants were classified as normal. On the mini-mental state exam, the mean score out of 30 for the potroom group was 29.4 and for the comparison group it was 29.2.

Thirty-three (52%) of the potroom group and 15 (41%) of the comparison group were found to have at least one neurologic abnormality. The odds ratio was 1.62 with a 95% confidence interval of 0.71-3.67. Nine of the 33 people with neurologic abnormalities in the potroom group were noted to have tremor, usually of the upper limb, but in one case, of the head. Five of the 15 people with neurologic abnormalities in the comparison group were also noted to have tremor. Three of the potroom group had unsteadiness on tandem gait, while no workers in the comparison group had this abnormality. No significant differences were found between the groups for

any of the neurologic exam abnormalities relevant to the postulated potroom-related disorders. There were several other abnormalities found for which non-occupational causes were present, such as diabetic neuropathy, familial drooping of the eyelids, and medication-induced upper extremity tremor.

Upper Limb Tremor

Tremor summary measurements were developed by fast Fourier transforming each sample measurement into a power spectrum of 256 discrete points covering a frequency range of 0-30 Hertz (Hz). This power spectrum provides a summary measure of amplitude of the tremor in both horizontal and vertical directions. Data reduction techniques were used to create 18 1-Hz power bands (1-18 Hz), which were transformed to natural logarithms for statistical analysis. Two statistical analyses were run:

1. An analysis of group differences using repeated measures analysis of variance (ANOVA) for both power (amplitude) and frequency; and

2. A Chi-square analysis of the distribution of individual scores.

Both types of analysis were run with and without former workers and compensation claimants.

To test for differences between the groups, the measurements were subdivided into those that characterized visible tremor (1-6 Hz) and those that characterized part of the non-visible tremor range (7-12 Hz). No analysis was performed on the remainder of the non-visible range (13-18 Hz) as the power in this frequency band was too low to be meaningful.

A fatigue effect was found for both visible and non-visible tremor, characterized by an increase in tremor over time, confirming the sensitivity of the tremor test. To control for the effect of the fatigue variable, the analysis comparing the groups was performed only for the measurements in minute two of the three minute testing period. Subject measurements in the second minute were less variable because they were not still correcting their target aim (which tends to occur in minute one) and the fatigue effects were not yet present (fatigue effects tend to maximize in minute three).

The results shown in Table 3 indicate no significant differences between the groups on power (amplitude) nor frequency for both the visible and non-visible range of arm tremor in both horizontal and vertical directions. Repeating the analysis with former and compensation workers excluded made no difference to these findings.

The purpose of the Chi-square analysis was to determine whether there were more extreme scores indicative of clinical tremor in the potroom group. Power measurements of tremor in both the visible and non-visible range in minute two were arranged into deciles and the two study

groups compared on the same tremor power parameters as outlined in Table 3. No statistically significant results were found. When this same analysis was performed for power at peak frequency in the visible and non-visible range, a statistically higher ($p=0.02$) result was found for the potroom group only in the non-visible range in the vertical direction. All other results were normal. The clinical relevance of this isolated finding is not clear.

To investigate agreement between tremor measured by the hand held device and neurologic examination, the measurements in the 8th, 9th, and 10th deciles were compared with the examination of tremor by the neurologist. The agreement was very high (>85%) for three measures and 75% for a fourth measure.

Leg Tremor

The statistical analyses performed to evaluate group differences for leg tremor were the same as the first analysis described above for the hand/arm tremor device. This was an analysis of group differences using repeated measures ANOVA for both power (amplitude) and frequency. No comparisons were done with the neurologist examinations because the neurologist did not examine for leg tremor. This analysis was confined to the measurements from minute two to control for the fatigue effect which was found to cause increased tremor in minute three.

The results for leg tremor are reported in Table 4 and show similar results between the two groups on all power (amplitude) and frequency measures. Similar to the conclusions for hand/arm tremor, the leg tremor measurements showed sensitivity to fatigue effects, but there were no exposure group differences.

Postural stability

Postural sway path length and mean radius are clinically relevant parameters measured by the postural stability test. No significant differences between the potroom and comparison groups were found for these two parameters for any of the test conditions. Table 5 presents the results for each group for the mean radius parameter, measured in inches, for the 12 test conditions. Further analysis was undertaken to look for interactions between different test parameters, using the raw data and ratios of the raw scores. Although there were a few isolated statis-tically significant findings, mainly for the mean radius parameter, most of this analysis found no significant differences between the groups. There was insufficient concurrence among the parameters of path length, area, and mean radius to suggest any neurologically meaningful differences.

Reaction time

The mean reaction time and the mean standard deviation were computed for each participant across all trials. In addition, the fastest and slowest reaction times were recorded for each. Two

participants whose fastest reaction times were less than 100 msec., were most likely not following instructions and were omitted from the analyses. Also, one participant could not complete the reaction time test due to disability, and another due to equipment failure.

The mean reaction time for the 59 potroom workers was 279.1 msec.(s.d = 55.93), and the mean reaction time for the 37 comparison workers was 261.8 msec (s.d = 45.22); these were not statistically different [$F(1, 94) = 2.06, p = .1548$]. The means of the two groups are similar to those obtained in a previous NIOSH study of 932 subjects evaluating reaction time, using the NCTB reaction time test (Anger et al. 1993).

Vocabulary test

Scores were obtained for each participant on the vocabulary portion of the WAIS-Ra (Wechsler 1981). Four workers (one from the potroom and three from the cast house/carbon plant) were excluded from all analyses of vocabulary scores because they reported that their primary language was Spanish. The mean vocabulary score for the 62 potroom workers was 44.8, and the mean score for the 34 comparison workers was 41.5. The difference between the means of the two groups was not significant [$F(1, 94) = 1.82, p = .1807$].

DISCUSSION

One of the objectives in the design of this cross-sectional study was to include former workers in order to reduce the effect of a survivor bias on the results. A survivor bias occurs when workers who develop the disease being investigated are more likely to have left the workplace than those workers not affected. This bias tends to underestimate the true relationship between workplace risk factors and the disease being studied, because the workers who are in better health tend to remain in the workforce. Despite multiple attempts to identify and contact eligible former workers in each group in this study, participation rates were very low, especially for the non-potroom former workers. Therefore, there is a possibility that survivor bias accounts for a reduction in the reported prevalence of disease in the studied groups.

The demographic characteristics (age, educational level, and race) of the two groups were very similar. Therefore, any differences in health outcomes between the two groups are not likely to be due to these characteristics.

The prevalences of neurologic symptoms were consistently higher in the potroom group, although a statistically significant difference between the potroom and comparison groups was found only for the incoordination symptom. Borderline statistical significance was found for two other symptoms; difficulty buttoning clothes and depression. However, the confidence intervals were very wide due to the relatively small numbers, causing a low degree of precision in the odds

ratios. The finding of higher neurologic symptom reporting rates in the potroom group is consistent with the findings of a consultant's unpublished 1992 telephone survey of neurologic symptoms among Intalco workers.

Because of the large amount of previous publicity within the plant regarding the possibility of neurologic problems among potroom workers, and the fact that several previous studies have been conducted on these workers, the possibility of an information bias operating among the potroom workers cannot be discounted. An information bias is said to be operating when members of one of the groups under study (usually the exposed group), because of previous knowledge about the health outcome and exposure being investigated, are more likely to report symptoms because they can anticipate the 'correct' answers. This bias only operates in the case of the collection of subjective data, such as symptom reporting, and could be minimized by conducting a similar study of workers in a different plant, who are unaware of the biasing information.

As it had been anticipated that an information bias may be operating among workers at the Intalco plant, the study incorporated several objective measures of both motor and cognitive function. Objective indicators of neurologic impairment are an important part of any study investigating neurologic abnormalities in workers exposed to suspected neurotoxins. This is because they are able to detect abnormalities in both the clinical and subclinical range, and they can test consistency with subjective indicators of neurologic disorders, such as symptom reporting.

The neurologic exam found high rates of neurologic abnormalities in both groups. However, most of the abnormalities were minor, did not relate to the prime neurologic problems of interest in this study (i.e., tremor or incoordination), or had an apparent non-occupational cause (i.e., diabetes or familial). Although there was no difference between the two groups in prevalence of tremor found on neurologic exam, the exam is only able to detect tremor in the visible range, i.e., in the frequency range of 1-6Hz.

Objective tremor testing of both hand/arm and leg found no differences between the potroom and comparison groups. This was true for tremor in both the visible and non-visible range. Therefore, these findings did not support the finding of increased symptom reporting for tremor in the potroom group. The tremor test was found to be sensitive to fatigue effects, and this effect was controlled in the analysis by analyzing data collected in the second minute of testing.

There were no significant differences between the two groups in either the postural sway path length or mean radius or the clinically relevant parameters in the postural stability test. Although the postural stability test demonstrated some isolated statistically significant differences between the potroom and comparison groups for some interactions between test parameters, there was insufficient concurrence among the parameters of path length, area, and mean radius to suggest that these were neurologically meaningful differences. These inconsistent

findings, and the likelihood that unique sensory systems may have been differentially involved in the results, strongly suggest that testing which identifies the separate capacities of visual, proprioceptive, and vestibular functions should be used in future studies of postural stability in aluminum workers.

No differences were found between the groups on either reaction time or vocabulary score. The mean reaction times were similar to values found in other populations (Anger, 1993), suggesting that simple visual-motor function was not impaired in either group. The lack of a difference in mean vocabulary score suggests that baseline levels of verbal intelligence were similar in both groups. Also, examination of vocabulary scaled scores for each WAIS-Ra age group found that 96% of the workers were within one standard deviation of the general population mean, suggesting that vocabulary scores of both groups of workers were not different from the general population.

It should be stressed that the members of each study group were selected on the basis of long term employment in the plant, starting at a time when aluminum exposure in the potroom was higher than it is today due to the absence of hoods on the pots prior to 1972. As neurologic impairment due to chemical exposure is usually slowly progressive, the inclusion of groups of workers with at least 23 years since first exposure (i.e., all workers in the study commenced work at the plant prior to January 1, 1970) ensures that an appropriate latent period was built into the study design. This entrance criterion was used to maximize the chances of finding evidence of neurologic abnormalities, if present, in the most heavily aluminum exposed sub-group in the plant in terms of air levels and years of exposure.

Because of the presence of potential biases in this HHE, a further prospective study of long-term aluminum exposure in potroom workers in a different reduction plant may be required to answer more definitively the questions posed in this HHE.

CONCLUSIONS AND RECOMMENDATIONS

1. Objective indicators of neurologic impairment (clinical neurologic examination, hand/arm tremor testing, leg tremor testing, and postural stability testing) did not show evidence of an association between potroom work and tremor or incoordination.

2. Higher reporting rates of neurologic symptoms were found for the potroom group. Although these subjective findings were not supported by results of the clinical and objective testing for tremor and incoordination, symptoms without physical findings may be indicators of early neurologic problems. Workers experiencing adverse symptoms should be encouraged to seek further medical evaluation. Prompt medical evaluation of employees with symptoms should be available without fear of supervisor or employer reprisal.

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3. OSHA Region X - Seattle

For the purpose of informing affected employees, copies of this report shall be posted by the employer in a prominent place accessible to the employees for a period of 30 calendar days.

TABLE 1
Demographic Characteristics of Potroom and Pomparison Groups
HETA 90-0149 - Intalco Aluminum Corporation
Ferndale, Washington

Group	Age in years mean (sd) range	Race		Education level	
		White	Non- white	Less than 12 years	At least 12 years
Potroom (63 workers)	54.0 (6.2) 48.3 -- 68.4	57 (90%)	6 (10%)	15 (24%)	47 (76%)[1]
Comparison (37 workers)	53.9 (7.4) 43.5 --74.9	30 (81%)	7 (19%)	8 (22%)	29 (78%)

[1] Based on 62 workers only

TABLE 2
Neurologic Symptoms Reported by Potroom Workers Compared with Casthouse/Carbon Plant Workers
HETA 90-0149 - Intalco Aluminum Corporation
Ferndale, Washington

Variable	Prevalence Potroom group	Prevalence comparison group	Odds Ratio	95% Conf. Int. (exact)
Tiring	27.0%	10.8%	3.05	(0.87, 13.47)
Memory trouble	30.2%	21.6%	1.57	(0.56, 4.69)
Difficulty Concentrating	19.0%	8.1%	2.67	(0.65, 15.67)
Confusion	9.5%	0%	5.15 MUE*	(0.94,)
Difficulty Understanding	7.9%	2.7%	3.10	(0.33, 150.8)
Incoordination	17.5%	0%	10.59 MUE*	(2.11,)
Imbalance	14.3%	2.7%	6.00	(0.76, 270.2)
Difficulty Buttoning	11.1%	0%	6.16 MUE*	(1.16,)
Difficulty Writing	6.3%	0%	3.23 MUE*	(0.54,)
Shaking	15.9	5.4	3.30	(0.64, 32.46)
Appetite loss	3.2%	0%	1.43 MUE*	(0.17,)
Depression	11.1%	0%	6.16 MUE*	(1.16,)
Weight Loss	0%	5.4%	0.24	(0.00, 2.02)
Irritable	9.6%	2.7%	3.79	(0.43, 179.1)
Mood Changes	12.7%	2.7%	5.24	(0.65, 238.7)

* MUE = Median unbiased estimate

TABLE 3
Log Power Values and Peak Frequencies for Arm Tremor for Minute Two for Potroom and Comparison Groups HETA 90-0149 - Intalco Aluminum Corporation Ferndale, Washington

Arm Tremor	Potroom Group	Comparison Group
Total Power (1-6Hz)[1]		
Horizontal	46.84 (5.38)	46.76 (3.39)
Vertical	48.66 (5.07)	48.19 (3.32)
Total Power (7-12Hz)[1]		
Horizontal	51.92 (5.57)	52.09 (4.68)
Vertical	48.57 (5.11)	49.06 (3.90)
Peak Frequency (1-6Hz)[2]		
Horizontal	3.21 (1.74)	3.40 (1.85)
Vertical	2.42 (0.97)	2.59 (1.38)
Peak Frequency (7-12Hz)[2]		
Horizontal	8.42 (1.02)	8.54 (1.04)
Vertical	9.02 (1.50)	8.95 (1.56)

[1]Power is a measure of amplitude with means and (standard deviations) expressed as power units of log transformed measurements (meters/sec.^{2}).
[2]Means and (standard deviations) are expressed in Hertz units.

TABLE 4
Log Power Values and Peak Frequencies for Leg Tremor for Minute Two for Potroom and Comparison Groups HETA 90-0149 - Intalco Aluminum Corporation Ferndale, Washington

Leg Tremor	Potroom Group	Comparison Group
Total Power (1-6Hz)[1]		
Horizontal	45.25 (5.23)	45.29 (6.21)
Vertical	60.92 (6.19)	58.62 (6.34)
Total Power (7-12Hz)[1]		
Horizontal	16.94 (4.72)	16.62 (4.76)
Vertical	29.22 (7.67)	27.01 (6.94)
Peak Frequency (1-6Hz)[2]		
Horizontal	1.83 (0.46)	1.86 (0.54)
Vertical	2.28 (0.88)	2.46 (0.84)
Peak Frequency (7-12Hz)[2]		
Horizontal	7.13 (0.47)	7.03 (0.16)
Vertical	7.35 (0.82)	7.59 (0.98)

[1]Power is a measure of amplitude with means and (standard deviations) expressed as power units of log transformed measurements (meters/sec.^{2}).
[2]Means and (standard deviations) are expressed in Hertz units.

TABLE 5
Raw Mean Radius Scores (Inches) in the 12 Test Postural Stability Series
HETA 90-0149 - Intalco Aluminum Corporation
Ferndale, Washington

GROUP		HEO1		HEC1	
		Mean	SC	Mean	SC
Comparison		0.212	0.0599	0.275	0.0683
Potroom		0.224	0.0793	0.304	0.1389
		SEO1		SEC1	
Comparison		0.248	0.074	0.394	0.1383
Potroom		0.274	0.0982	0.394	0.134
		HEO2		HEC2	
Comparison		0.22	0.0619	0.261	0.0779
Potroom		0.231	0.1038	0.314	0.1392
		SEO2		SEC2	
Comparison		0.238	0.0646	0.372	0.1445
Potroom		0.287	0.1138	0.389	0.1229
		LL1		RL1	
Comparison		0.366	0.3734	0.375	0.0793
Potroom		0.382	0.0769	0.429	0.1546
		LL2		RL2	
Comparison		0.354	0.0737	0.387	0.0996
Potroom	N	8 0.37	994 0.0	0.401	0.1018