

## Health implication among occupational exposed workers in a chromium alloy factory, Thailand

S. Muttamara, Shing Tet Leong\*

(Research Lab Supervisor, Urban Environmental Engineering and Management Program, School of Environment, Resources and Development, Asian Institute of Technology, G.P.O. Box 4, Klong Luang, Pathumthani 12120, Thailand. E-mail: tet@ait.ac.th)

**Abstract:** This study was conducted to assess the occupational exposure and its health impact on the chromium alloy workers. Environmental and biological monitoring, noise and audiometry measurements were done to evaluate the exposure levels in the factory. A total of 112 non-smoking workers were monitored from July 2001 to August 2002. The results showed that most of the chromium and lead exposures in the factory were below the ACGIH-TWA of 50  $\mu\text{g}/\text{m}^3$  for chromium(VI) and OSHA-PEL of 50  $\mu\text{g}/\text{m}^3$  for lead. The highest chromium ( $7.25 \pm 0.16 \mu\text{g}/\text{m}^3$ ) and lead ( $14.50 \pm 0.29 \mu\text{g}/\text{m}^3$ ) concentrations were measured in the vibro room. The results indicated that elevated concentrations of chromium and lead were found in both blood and urine samples especially in those areas which were characterized by poor ventilation. The metal contents in blood and urine samples were significantly correlated with airborne metal concentrations in the factory. The result demonstrated that blood and urinary levels among workers were associated with increasing age and duration of exposure.

The background noise level of the factory ranged from 67.6 to 89.2 dBA and was frequently higher than the threshold limit value for noise (90 dBA). According to the audiometric test, the exposed workers showed signs of noise-induced hearing loss. Noise at work continued to be an important factor to hearing loss among exposed workers. In our statistical analysis, a significant hearing loss was established on age effect and year of exposure among the workforce.

**Keywords:** chromium and lead exposure; electroplating; environmental and biological monitoring; audiometry measurement

### Introduction

National Statistical Office, Thailand (NSO, 2000) reported that the need for metal manufacturing industries and associated production sector has increased at an extremely rapid rate, especially in the central part of Thailand. It is estimated that there are more than 1000—3000 registered electroplating shops in Bangkok Metropolitan Region (BMR), ranging from small, medium to large scale. A typical process of chromium plating consists of polishing, degreasing, chemical cleaning, pickling and electroplating (IAMS, 1999). In physical cleaning operations, dusts are released into the environment. Degreasing operations may result in solvent bearing wastewater, air emissions and material in solid form. During the chemical process, the products pass through chemical baths in various sequences. They are normally rinsed with water in order to remove traces of the bath liquor from the surface of the metal (Schneider, 1989). The principal wastes from cleaning step include alkaline cleaning solutions (sodium salts of phosphates, carbonates, silicates and hydroxides), acidic cleaning solutions (nitric, sulfuric and hydrochloric) and organic acids (sulfamic, acetic and oxalic). Electroplating processes create a considerable amount of toxic heavy metal wastewater, which is highly

corrosive. The discharge of untreated metal finishing wastewater to natural waterways is detrimental to flora and fauna of streams and has contributed damage to natural ecosystems (UNEP/IEO, 1989). Emissions of substances in electroplating waste to the atmosphere may occur by volatilization of gas-phase and semi-volatile compounds, such as acid mists from plating bath, solvent vapors from degreasing process, dust from mechanical cleaning and chromium vapors from plating and anodizing process.

In addition, a significant amount of manganese, lead, chromium, nickel and other trace elements are emitted from engine repair, spray painting and welding works (Liss, 1996). Recent studies of chromium platers and stainless steel welders have been found to have excess lung cancer (Royle, 1975). Acute inhaled exposure to chromium can cause coughing, wheezing and fever, and may lead to kidney damage (ATSDR, 1993). Breathing in high levels of chromium(VI) can cause asthma attacks and is believed to be primarily responsible for the increased lung cancer rates in workers (Angerer, 1987). Lead exposure is the oldest known occupational epidemiology. Abdominal pain, tiredness and irritability commonly characterize acute lead poisoning in adult. Chronic exposure to lead can adversely affect human health including neurological, gastrointestinal and renal

\* Corresponding author

impairments (EEP, 1997).

In addition to welding fumes, dust, paints and solvent exposures, workers in the chromium alloy factory are occupationally exposed to excessive noise levels. The noise generated by blending, vibro room and grit blasting area presents problems to the workers. The source of noise comes mainly from metal finishing operations and is a major cause of noise-induced hearing loss among workers.

The rapid expansion of the chromium alloy industry in Thailand will continue to be a serious threat to the environment and quality of life in rural areas unless mitigation measures of environmental contaminants from chrome alloy waste have received wide attention by factories to initiate cleaner production and waste minimization. The main objective of this study was to carry out environmental (analysis of heavy metal in the air) and biological (analysis of heavy metals in blood and urine) monitoring, background noise monitoring and audiometry of workers.

## 1 Materials and methods

### 1.1 Study site

The selected factory is situated at Pathumthani, a province of the Bangkok Metropolitan Region (BMR), Central Thailand. The total land area of the factory is 22836 m<sup>2</sup> including 9000 m<sup>2</sup> of available land area for wastewater treatment system. The factory works on a two shift day (16 h/d) and employs 340 workers. Male workers dominate about 80% of the total workforce. The factory performs metal finishing works for air craft, industrial, turbine and honeycomb components.

### 1.2 Study groups

A total of 112 non-smoking workers were selected for the study groups and represented 20% of the daily occupationally exposed workforce. Their daily working time ranged from 8 to 14 h and had an average pollutant exposure dose of 83% to 94%. The response of factory workers was good and there is no refusal among selection because of prior consultation with the factory management. Males are predominated in the work force with 39.3 average year old. The working group was further classified into different age groups (16–25, 26–35, 36–45 and 46–55 years old) and service groups (1–8, 9–16, 17–24 and 25–32 service years) to provide better indication of pollutant exposure due to aging and year of service. The eligible study groups were checked for medical history and socio-economic lifestyles, which are useful factors for the occupational exposure assessment. Control groups of 28 persons (25% of the study groups) were selected from those who were non-occupational exposure to air pollutant and spend most of their time, work primarily in air-conditioned indoors. They were expected to have lower pollutant exposure because indoor air pollution level was much different from outdoor level.

### 1.3 Airborne particulate matter

Airborne particulate chromium and lead samples are collected in the grit blasting area, chemical room, vibro room, blending and welding areas. Sampling for airborne particulate can be accomplished by using a personal air-sampling pump (SKC model 224-PCXR8) with 1–3 L/min flowrate and 0.8 µm cellulose ester membrane filter in 37 mm diameter cassette filter holder. After sampling, particulate chromium sample is digested in accordance to NIOSH's Analytical Method 7024 (NIOSH, 1994). Likewise, the particulate lead sample is digested with mixture of 3:1 (v/v) HNO<sub>3</sub>:H<sub>2</sub>O<sub>2</sub> and diluted with distilled water (P&CAM7105, NIOSH, 1990). Measurements of chromium and lead in blood or urine are considered the most useful tool for screening and assessing exposure. The blood collection (5 ml/sample) is performed using Venoject glass vacuum tubes and immediately transferred to the laboratory for analysis. The blood sample is digested by mixture of 3:1:1 (v/v/v) HNO<sub>3</sub>:HClO<sub>4</sub>:H<sub>2</sub>SO<sub>4</sub> (P&CAM8005, NIOSH, 1985). The urine samples were collected in polycarbonate bottles, during the work shift (8 h). The urinary samples are extracted with polydithiocarbamate resin, filtered on cellulose ester membrane, neutralized by sodium hydroxide solution, followed by ashing, dissolution, heating and diluting with distilled water (P&CAM8310, NIOSH, 1984).

All analytical measurements for chromium and lead in biological samples is conducted by graphite furnace atomic absorption spectrometry (Hitachi Z-8230) with Zeeman background correction that can minimize the impact of the absorbency of molecular species. The detection limit for blood and urinary samples are 0.01 µg/g and 0.005 µg/ml, respectively. Calibration was performed using external standards prepared from a set of corresponding standard solutions.

### 1.4 Ambient noise measurement

Noise level at each monitoring area was measured by using a precision integrating sound level meter (RION, NL-14, Japan) confirming to the International Electrotechnical Commission Recommendations (IEC, 1987). The microphone (RION, UC-53) of the precision integrating sound level meter (RION NL-10) was placed at the level of the worker's ear (1.5 m above the ground). Each day before starting a measurement, acoustic calibration was performed using the piston-phone (RION, NC-72) or sound level calibrator NC-73. The equivalent continuous sound level for an eight-hour work day or the  $L_{eq}$  (8 h) was measured for the octave band frequency with the sound level meter fitted with octave band filter RION NX-01A unit (RION, NX-05). A noise dosimeter (Cole-Parmer, U-01621-01) is used to give accumulated exposure dosage over a prescribed period of time and registers it as a percentage (% dose) of the reference  $L_{eq}$  (dBA level). Environmental parameters, such as ambient temperature, relative humidity and wind velocity were

recorded together with the sound measurements.

### 1.5 Measurement of hearing level

In this study, the factory was visited twice to collect basic information for noise measurements. The eligible study group must satisfy an otoscope examination to check the inner and outer part of the ear under the supervision of an audiologist. They must be free from any injury to external ear canal and ear drum, absence of ear wax, free from any kinds of diseases and no family history of hearing loss before the age of 50. Automatic audiometers (Grason-Stadler, model 1703B) with test frequencies including 250, 500, 1000, 2000, 3000, 4000, 6000 and 8000 Hz were used for the audiometric measurement. The audiometric tests were conducted in a prefabricated and sound insulated test booth (1.3 m (L), 1.2 m (W) and 2.25 m (H)). The ambient noise levels inside this room conform to all requirements by ANSI S3.1-1991 (ASA99).

### 1.6 Statistical analysis

All analytical measurements are performed in triplication to give mean values with standard deviation. In all statistical analysis, every effort is ensured that chromium and lead concentrations were kept below the minimum detection limit of the laboratory methods. In order to find out the biological monitoring effects on chromium/lead concentration in assessing exposure, statistical analysis was carried out. One-way analysis of variance (ANOVA) was used to determine the statistically significant difference between each assessing exposure with respect to a control treatment. In addition, statistical program (SPSS version 10.0) and the non-parametric test (Mann-Whitney U test) was used to analyze the differences between exposed and control groups.

## 2 Results and discussion

### 2.1 Air and biological survey

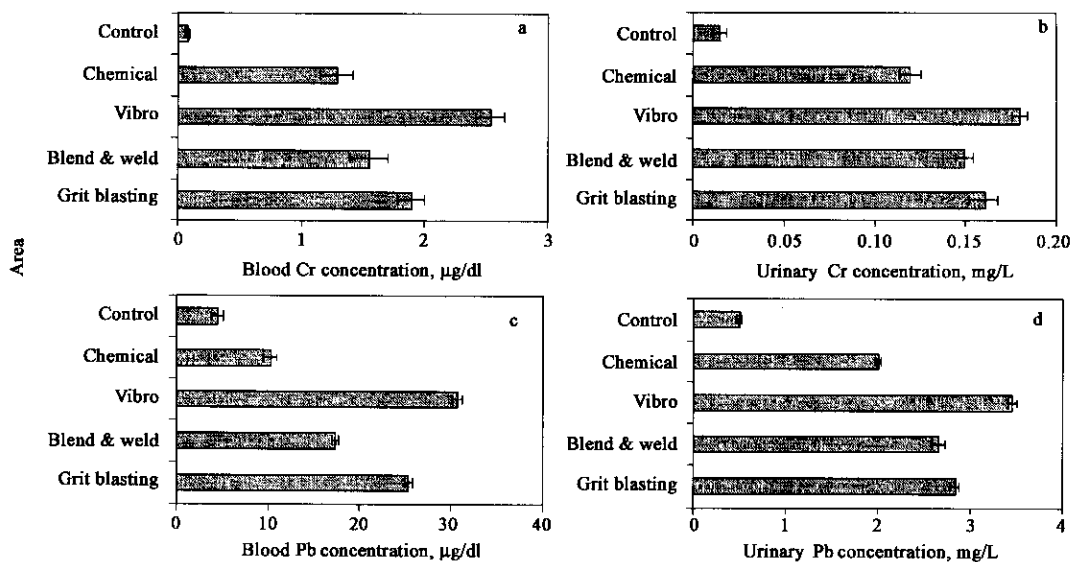


Fig.1 Biological concentration of (a) blood Cr, (b) blood Pb, (c) urine Cr and (d) urine Pb of exposed workers collected from various working areas in the factory

### 2.1.1 Blood chromium and lead concentrations

Fig.1a shows that there are variation in blood chromium concentration at different working area in the factory (grit blasting:  $1.89 \pm 0.11$  µg/dl, chemical room:  $1.28 \pm 0.14$  µg/dl, vibro room:  $2.53 \pm 0.12$  µg/dl and blend & weld area:  $1.55 \pm 0.16$  µg/dl). For control group, the median level of blood chromium concentration is  $0.08 \pm 0.01$  µg/dl. Significant difference was established between the nonsmoking exposed group and nonsmoking control group for blood chromium concentrations ( $P < 0.001$ , two-tailed, Mann-Whitney U test).

The blood lead concentrations of exposed workers collected from the factory (ranging from chemical room:  $10.15 \pm 0.74$  µg/dl to vibro room:  $30.60 \pm 0.56$  µg/dl) are given in Fig.1b. The results were similar to previous study conducted by Centers for Disease Control and Prevention (CDC, 1995) which reported that the Taiwanese soldering workers of battery plant has blood lead concentrations of 34.6 µg/dl. The Occupational Safety and Health Administration; Lead Standard (OSHA, 1978) specifies a blood lead level of greater than 40 µg/dl requires medical intervention. A blood lead level of 60 µg/dl or three consecutive blood lead levels above 50 µg/dl, the worker should be removed from further exposure. It is desirable for all workers to minimize their occupational exposure to lead and maintain their blood lead level below the national standard of 25 µg/dl. Research into the detrimental effects of lead poisoning on human health showed that blood lead levels of 50–80 µg/dl can cause chronic kidney deterioration in adult and severe nerve damage in children (Waldren, 1974). Recent studies of background blood lead levels on children reported that even at low blood lead level of 10 µg/dl, it could affect nervous system (Ruangkanchanasetr, 1994).

### 2.1.2 Urinary chromium and lead concentrations

In Fig. 1c, it can be seen that urinary chromium concentrations at vibro room ( $0.18 \pm 0.004$  mg/L) and grit blasting area ( $0.16 \pm 0.008$  mg/L) were higher than blend and weld area ( $0.15 \pm 0.005$  mg/L) which was in turn higher than chemical room ( $0.12 \pm 0.006$  mg/L). The median level of urinary chromium among control groups was 0.015 mg/L. In most cases, higher urinary metal concentrations in workers are found in those working area with high airborne metal content while lower urinary metal concentrations are those in lesser metal exposure area. A significant difference was statistically established between exposed and control groups for urinary chromium concentrations ( $P < 0.01$ , two tailed, Mann-Whitney U test). In addition, a variety of factors can affect the level of chromium excretion. These factors include body mass, age, gender, dietary intake as well as smoking (USEPA, 1984).

Analytical results in Fig. 1d indicate that urinary lead concentrations among exposed workers were found to be in the range  $2.00 \pm 0.03$ – $3.45 \pm 0.04$  mg/L. In any case, to conform our study, the mean urinary lead concentrations of different exposed groups were compared with that of control groups (non-exposed groups). The results revealed that the urinary lead concentrations in the control group were remarkably lower than that of the study groups at all monitoring areas.

### 2.1.3 Age-related exposure

Fig. 2 shows the relationship between different age groups of exposed workers and biomarkers with respect to chromium/lead concentrations in blood and urinary samples. In general, chromium/lead concentrations in bio-samples were normally increasing with age when the subjects were constantly exposed to excessive pollutant exposure. Throughout the monitoring period, it was found that the tested group of 46–55 years old had the highest blood chromium concentration ( $3.63 \pm 0.20$  ppt) than the 16–25 year groups ( $0.92 \pm 0.04$  ppt). The analytical finding revealed that

younger adult group (16–25 years old) perceives lower chromium exposure than other older age groups (Fig. 2a). Similarly, it can be seen from the graph (Fig. 2b) that blood lead data collected on older adults (46–55 years old) showed higher blood lead concentration ( $48.95 \pm 1.52$ ) than other younger age groups of the same monitoring area.

Comparing the urinary Cr/Pb data collected for the 46–55 year group (Fig. 2c and 2d), they demonstrated to have higher urinary Cr/Pb concentration relative to the younger age groups who were not so exposed to excessive Cr/Pb pollution. In any case, to conform our study, the mean urinary Cr/Pb concentrations of different age groups were compared with that of control groups (non-exposed groups). The results revealed that the urinary Cr/Pb concentrations in the control group were remarkably lower than that of the different age groups. This suggested that the increase reflect the overall age effect. The sequence of atmospheric chromium and lead concentrations for various age groups is 46–55 > 36–45 > 26–35 > 16–25.

### 2.1.4 Biomarkers versus airborne metal contents

The result delineated that airborne samples from vibro room and grit blasting area were found to have comparatively higher in chromium ( $7.25 \pm 0.16$   $\mu\text{g}/\text{m}^3$ ) and lead ( $14.50 \pm 0.29$   $\mu\text{g}/\text{m}^3$ ) concentrations than those of other areas. In contrast, the control area (office) had a significantly lower in chromium ( $0.25 \pm 0.07$   $\mu\text{g}/\text{m}^3$ ) and lead ( $1.06 \pm 0.18$   $\mu\text{g}/\text{m}^3$ ) concentrations than those of other areas. The finding shows that average chromium and lead concentrations in air were within standard level. The American Conference of Governmental Industrial Hygienists (ACGIH, 1996) has suggested a TLV-TWA of 50  $\mu\text{g}/\text{m}^3$  for chromium (VI) exposures. Likewise, the Occupational Safety and Health Administration (OSHA, 1978) specifies a permissible lead exposure limit (PEL) of 50  $\mu\text{g}/\text{m}^3$  over an 8-h period.

In this study, regression analysis was used to establish correlation between airborne metal concentration and the

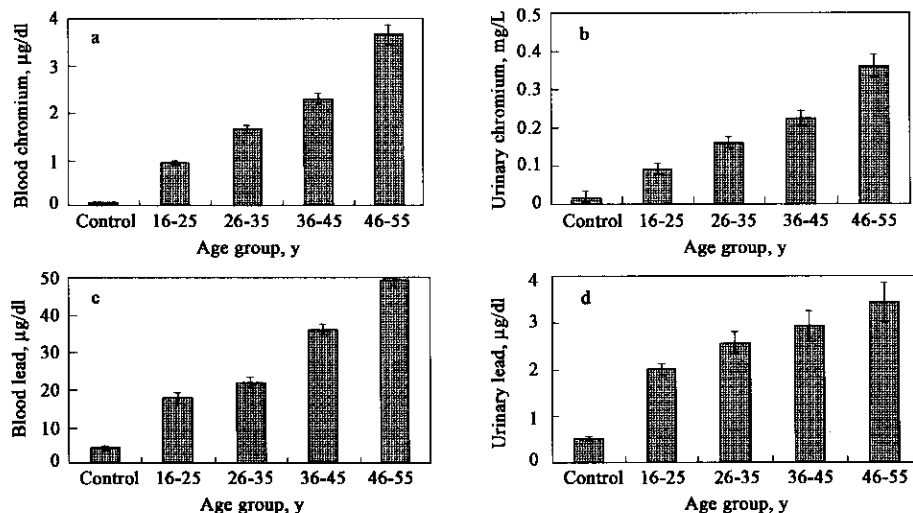


Fig. 2 Biomarker of exposed workers with respect to (a) blood chromium, (b) blood lead, (c) urinary chromium and (d) urinary lead for different age groups ( $n = 112$ )

chromium and lead values in bio-samples. It would help to understand the relationship between environmental media of workplace and personal exposure. Significant positive correlations were obtained between airborne chromium concentration and chromium biological (blood and urine) values. The correlated coefficients  $R^2$  shown in Fig. 3 are greater than 0.9. Similarly, good correlation is also

established between all of the lead biomarkers and lead concentration in air. This was further supported by the comparison between study and control groups based Mann-Whitney U test, which showed a statistically significant level of  $P < 0.001$ . From this result, it is shown that chromium-alloy workers have a higher risk of chromium and lead exposure than general population.

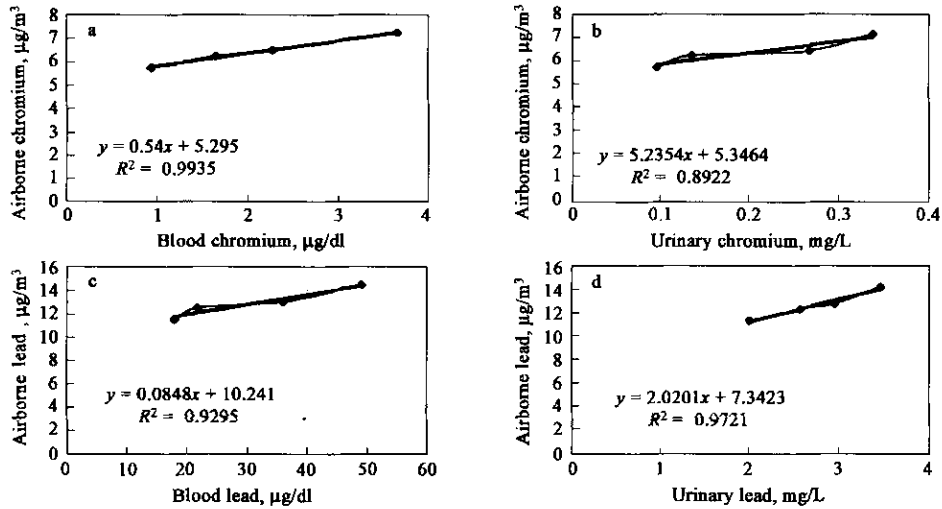


Fig.3 Correlations between (a) blood chromium, (b) urinary chromium and chromium in air for the exposed workers

Area	Blood chromium		Urinary chromium	
	Blood Cr, $\mu\text{g/dl}$	Cr in air, $\mu\text{g/m}^3$	Urine Cr, $\mu\text{g/dl}$	Cr in air, $\mu\text{g/m}^3$
A1	3.63968	7.25	0.3368	7.25
A2	2.26368	6.5	0.2668	6.5
A3	1.635	6.25	0.135	6.25
A4	0.925	5.75	0.095	5.75

2.2 Noise and hearing survey

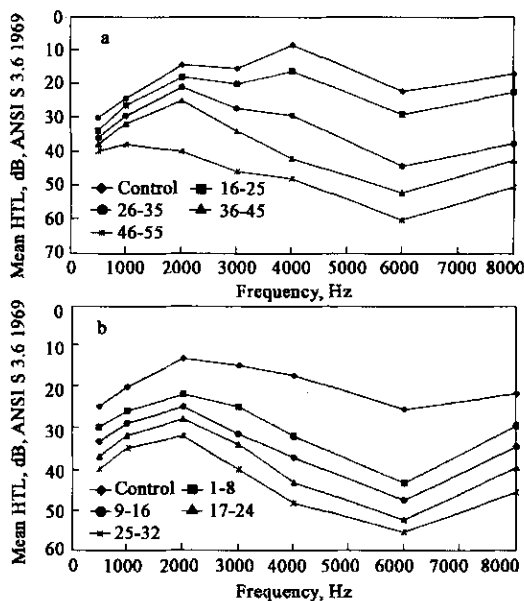


Fig.4 Mean hearing threshold levels(HTL) for factory workers based on (a) age groups and (b) service groups

showed the noise level ranged from 67.6 to 89.2 dBA. About one third of the employees worked in locations where the  $L_{eq}$  (8 h) was 80 dBA and more. Machines in the blending areas and the air pressure gun in the vibro room generate high level of noise, which is more than 80 dBA. The dominant factors affecting earing loss were age, gender, duration and intensity of noise exposure (Suter, 1991). The pure-tone audiograms (Fig. 4a) shows that workers had magnitude of hearing deficit of 18 to 40 dB units for 500, 1000 and 2000 Hz. Hearing loss was found to increase between 10 year age groupings. The hearing loss was also found to be lower from 500 Hz to 1000 Hz but diverged at higher frequencies of 2000 to 8000 Hz. Noise induced hearing loss at 4000 and 6000 Hz (of 10 to 15 dBA loss) among workers was associated with increasing age and exposure to noise levels of  $L_{eq}$  (8 h) 80 dBA and more. According to the age groupings, the sequence of mean HTL for age group at the monitoring site is 46—55 > 36—45 > 26—35 > 16—25. Fig. 4b shows a similar variation of mean hearing threshold level(HTL, dB) in every service year groups. Comparing with the results, there was marked relative dip at 4000 Hz which suggested a clear audiometric evidence of occupational noise-induced hearing loss occurred in different service year groups in the factory. The result demonstrated that adverse health effect can happen to the exposed workers if the daily noise exposures were recurrented over several hours per day for months or years. The finding showed that the pattern of noise-induced hearing loss among workers was similar to those of metal press operators in Hong Kong (Lee, 1989).

Results of the noise level measurement in the factory

The Ministry of Interior sets the current workplace noise standard in Thailand to be  $L_{eq}(8\text{ h})$  90 dBA. The legal provisions are enforced by the Pollution Control Department (PCD, 1997). The findings in this study revealed that the occupational noise generated in most of the working areas inside the factory is exceeding the noise standard. The factory provides earplugs for all workers who work at these areas. The usage of earplugs was not satisfactory because only 25% of the workers use them at the time of work. Furthermore, warning notices depicting the harmful effects of noise and regular audiometric examinations of exposed workers are absent in the factory.

### 3 Conclusions

Environmental monitoring suggested that exposures to chromium for workers are below the ACGIH-TWA limit. However, USEPA reported that even at low chromium (VI) concentration of  $1\ \mu\text{g}/\text{m}^3$ , the lifetime cancer risk is estimated to be  $4 \times 10^{-2}$  (USEPA, 1984). Therefore, chromium (VI) and chromium (III) should be considered separately. This is, however, difficult as the information on speciation of chromium is derived from total chromium in ambient air. In addition, it is difficult to differentiate biological monitoring to Cr (III) from Cr (VI) in blood or urinary samples. Thus further research is needed to distinguish Cr (III) from Cr (VI) because of the greater toxicity of Cr (VI). Likewise, new and stronger measures are needed to control serious problems of lead proliferation in the working environment.

In a chromium alloy factory, noise pollution is a serious problem. Although legal provisions for the control of noise in workplace has been provided by the labor ordinance, the actual enforcement is less satisfactory. The present labor law should be amended to protect workers from noise-induced hearing loss.

### References

ATSDR (Agency for Toxic Substances and Disease Registry), 1993. Toxicological profile for chromium[S]. U.S. Public Health Service. TP-92/08, April.

ACGIH (American Conference of Governmental Industrial Hygienists), 1996. Documentation of threshold limit values for chemical substances and physical agents and biological exposure indices Cincinnati[S]. OH: ACGIH.

ANSI (American National Standard Institute), 1991. Maximum permissible ambient noise levels for audiometric test rooms[S]. New York, NY: American National Standard Institute, ANSI S3.1-1991(ASA 99).

Angerer J, Amin R W, Heinrich R, 1987. Occupational exposure to metals. I. chromium exposure of stainless steel workers-biological monitoring[J]. International Archives of Occupational and Environmental Health, 59: 503-512.

CDC (Centers for Disease Control and Prevention), 1995. Occupational lead surveillance-Taiwan, July-December 1993[EB]. Morbidity and mortality weekly report: 44(10): 181,187-189. Electronic Source: <http://www.cdc.gov/mmwr/preview/mmwrhtml/00036538.htm>.

EEP (Environmental Epidemiology Program), 1997. Adult blood lead epidemiology and surveillance project. Utah blood lead registry[EB]. 1996 Annual Report. Utah Department of Health. Bureau of Epidemiology. Electronic source: <http://hlunix.hl.state.ut.us/els/epidemiology/envepi/ables96.html>.

Hates R B, 1980. Cancer and occupational exposure to chromium chemicals[M]. In: Review in cancer epidemiology(Lilienfield A. M. ed.). Vol. 1. New York: Elsevier-North Holland. 293-333.

IEC(International Electrotechnical Commission), 1987. Sound system equipment part 16: Report on the RASTI method for the objective rating of speech intelligibility in auditoria[R]. Pub. 268.

IAMS(Institute of Advanced Manufacturing Science), 1999. What is metal finishing? [EB]. Electronic Source: <http://www.iams.org/iamsorg/p2iris/metalfinish/default.html>.

Lee L, Tan T C, 1989. Noise induced hearing loss among metal press workers [J]. Hong Kong Engin, 17: 9-11.

Liss G M, 1996. Health effects of welding and cutting fume: an update[EB]. Final report. Toronto, Ontario: Ontario Ministry of Labor, December 1996. 1-82 ([www.canoshweb.org/Odp/html/rp5.htm](http://www.canoshweb.org/Odp/html/rp5.htm)).

NSO(National Statistical Office), 2000. Statistical reports of region[R]. Office of the Prime Minister, Statistical Data Bank and Information Dissemination Division, Lam Luang Road, Bangkok 10100, Thailand.

NIOSH, 1984. Manual of analytical methods[S]. 3rd ed, Vol. 1. Method No. 7300, 8003 and 8310. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health.

NIOSH, 1985. Manual of analytical methods[S]. 3rd ed. Vol. 1. Method No. 8005. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health.

NIOSH, 1990. Manual of analytical methods[S]. 3rd ed. Vol. 1. Method No. 7105. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health.

NIOSH, 1994. Manual of analytical methods[S]. 3rd ed. Vol. 1. Method No. 7024. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health.

OSHA(Occupational Safety and Health Administration), 1978. Occupational exposure to lead: final standard[S]. U.S. Department of Labor, Occupational Safety and Health Administration. Federal Regist 1978; No. 29 CFR 1910.1025.

PCD(Pollution Control Department), 1997. Laws and standards on pollution control in Thailand[S].

Royle H, 1975. Toxicity of chromic acid in the chromium plating industry[J]. Environment Research, 10: 39-53.

Ruangkanchanasetr S, Santikarn C, 1994. Lead poisoning—a severe threat to the nation's health[J]. The Thailand Development Research Institute, 9(1): 21-27.

Schneider W, Fresenius W, Bohnke B *et al.*, 1989. Wastewater technology: origin collection, treatment and analysis of wastewater[M]. Vol 1, Berlin Heidelberg: Springer Verlag. 62; 183.

Suter A H, 1991. Noise and its effects[EB]. Administrative Conference of the United States: <http://www.nonoise.org/library/suter/suter.htm>.

United Nations Environment Program/ Industry and Environment Office, 1989. Environmental aspects of the metal finishing industry: a technical guide [R]. Technical Report Series No. 1.

USEPA (United State Environmental Protection Agency), 1984. Health assessment document for chromium[S]. United State Environmental Protection Agency, Research Triangle Park, NC (Final Report No. EPA600/8-83-014F).

Waldren H A, Stofen D, 1974. The sub-clinical lead poisoning[M]. London: Academic Press.

(Received for review January 21, 2003. Accepted March 6, 2003)