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Trace Metals in Chinese Joss Stick Smoke

T.-S. Lin,[1] F.-M. Shen[2]

[1] Department of Environmental Engineering and Health, Yuanpei Institute of Science and Technology, 306 Yuan-Pei Street, Hsin-Chu City, Taiwan 300
[2] Department of Medical Technology, Yuanpei Institute of Science and Technology, 306 Yuan-Pei Street, Hsin-Chu City, Taiwan 300

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The health effects related to exposure to incense smoke have been attracting more attention recently. The United States Environmental Protection Agency (EPA) (2001) is currently reviewing its potential health risk and trying to establish possible risk management options. The combustion of incense in daily religious worship is believed to be an important factor in the development of nasopharyngeal or lung cancer in Taiwan (Chen et al, 1990; Chen et al., 1987; Yu et al., 1990). The current estimated population at risk is approximately four fifths (80%) of Taiwanese and continues to increase owing to religious conversion (Lin, 1997). Investigations of health effects resulting from exposure to incense smoke have been focusing on organic compounds and particulate matter (Kao and Lung, 2000; Lin and Lee, 1998; Lee and Lin, 1996; Lin and Wang, 1994; Lin and Tang, 1994; Schoenotol and Gibbard, 1967). However, some field studies imply that levels of organic compounds or particulate matter owing to incense burning may not significantly influence human health as expected (Chao et al., 1997; Lung et al., 2001).

As a result of deposition of lead particles emitted from the burning of candles, and hand-to-mouth activities, the lead level in childrens' blood could elevate significantly (ATSDR, 1999; US EPA, 1998; IPCS, 1995). This phenomenon is a particularly significant cause for concern as Taiwanese ingest offerings after worship rituals, if a certain amount of toxic metals is released with regard to the Chinese joss stick burning. A family regularly engaged in this activity burns incense for approximately three hours daily. The composition of incense is complex and usually cheaply manufactured in family-type factories, which are often off record. An incense stick may be made of about 15 different varieties of dried and ground vegetation and a bamboo stick (Lee and Lin, 1996). The major contents of a Chinese joss stick are *Santalum album* L. (weight percentage: 32%), *Machilus nanmu* Hemsl. (weight percentage: 10%) and a bamboo stick (weight percentage: 33%)(Lee and Lin, 1996). This study aims to evaluate the concentration of trace metals in incense smoke and their potential health risk relating to religious worship in Taiwan.

Correspondence to: T.-S. Lin

MATERIALS AND METHODS

Three types of incense sticks with different colors （black, red, yellow） were chosen for this study because they are the most popular in Taiwan. The lengths of these black, red, yellow incense sticks are 36.3 ± 0.2, 37.4 ± 0.2, and 36.7 ± 0.08 cm, respectively. The weights of these black, red, yellow incense sticks are 2.24 ± 0.14, 2.32 ± 0.11 and 1.88 ± 0.12 g, respectively. They were all manufactured, and routinely burned in daily worship, in Taiwan. The experimental system consisted of a combustion chamber made of polypropylene (60 x 60 x 60 cm), fresh air supply unit and moisture production unit as well as sample collection units. Before being introduced into the combustion chamber, the air was pumped through prepurifying tubes containing charcoal or molecular sieve in order to provide uncontaminated air for experiments. The moisture production unit was utilized to maintain the relative humidity of testing atmosphere. The airflow was controlled at 9000 ± 500 mL/min by adjusting needle valves. The relative humidity was monitored by a sensor (Cole-Parmer 37950-12), and was set to be 70 ~ 88 % which was similar to the ambient condition in Taiwan. The temperature of combustion chamber during candle burning was approximately 38 °C, which was about 5 to 10 °C above ambient temperature. The trace metals were collected by a 37-mm cassette with cellulose ester membrane filter at a steady state for 120 minutes with a sampling rate of 1000 mL/min. The filters were dissolved by approximately 10 mL of heated concentrated nitric acid for 10 minutes and then the solutions were diluted to 25 mL. Three blanks were processed according to the same procedure as the samples except no Chinese joss sticks burning. This provided compensation for any possible contamination. All samples were analyzed three times by using a Perkin-Elmer Elan 5000 Inductively Coupled Plasma – Mass Spectrometer (ICP-MS). The operation conditions were as follows: 1) Carrier gas (argon, 99.999%): 0.8 L/min; 2) Plasma gas (argon, 99.999%): 15 L/min; 3) Auxiliary gas (argon, 99.999%): 0.8 L/min; 4) Pump rate: 1.5 mL/min; 5) Power: 1055 KW. The limits of detection of Cr, Co, Ni, Zn, Cd, Tl, and Pb were 39.4, 0.12, 8.7, 267.3, 125.6, 1.4, and 19.5 μg/L, respectively.

RESULTS AND DISCUSSION

The average emission rates of Cr, Co, Ni, Zn, Cd, Tl, and Pb resulting from incense combustion in the test chamber are 0.48 ± 0.46, 0.14 ± 0.05, 15.73 ± 6.83, 2.63 ± 2.37, 11.12 ± 10.48, 0.48 ± 0.46, and 0.11 ± 0.08 μg/hour, respectively (Table 1). The variation of trace metal emission rates, in addition to the trace metal content in raw materials, could be as a result of that the coating process of incense onto sticks is not standardized and not accurate. The emission rates are significantly higher than those observed in candle combustion tests, with the exception of Pb (Lin et al., 2003). This observation suggests that exposure to heavy metals from Chinese joss sticks burning during worship may be more significant than that from candle burning.

The levels of these metals in rooms may be estimated by their emission rates using the following equation:

$$C_t = \frac{G-(G-QC_0)e^{-\frac{Q(t-t_0)}{V}}}{Q}, \qquad (1)$$

Table 1. The emission rates of heavy metals during Chinese joss sticks burning (μg/hr).

	Cd	Co	Cr	Mn	Ni	Pb	Tl
Yellow	0.48	0.21	26.64	4.66	12.71	0.48	0.14
Yellow	0.18	0.06	6.62	0.95	2.89	0.18	0.05
Black	1.28	0.15	18.01	6.45	8.06	1.28	0.24
Black	0.73	0.14	13.59	1.91	31.43	0.73	0.14
Red	0.10	0.14	17.87	0.96	6.53	0.10	0.03
Red	0.13	0.12	11.64	0.82	5.09	0.13	0.05
Average	0.48	0.14	15.73	2.63	11.12	0.48	0.11
Standard Deviation	0.46	0.05	6.83	2.37	10.48	0.46	0.08

where G is the emission rate, Q the ventilation rate, V the room volume, C_0 the concentration at time t_0, and C_t the concentration at time t. The typical air exchange rate (AER) for homes varies from 0.25 to 0.5 turnover/hour (Li et al., 1994; Trayer et al., 1987; Tu and Knutson, 1988). However, very little or no air exchange in the room is a very common scenario during the winter period in Taiwan. Considering that one may burn Chinese joss sticks in the morning and evening every day, the fluctuation of concentrations of Cr, Co, Ni, Cu, Zn, Cd, Tl, and Pb, at varying air exchange rates, can be simulated by using equation (1). The estimated maximum concentrations of these metals in a 40 m^3 volume room, at AER 0 and 0.25 respectively, are shown in Table 2.

The major effects of cadmium poisoning are observed in the lungs, kidneys, and bones (Fergusson 1990). Inhalation of high levels of cadmium oxide fumes will result in tracheobronchitis, pneumonitis, and pulmonary edema (Donkin et al., 2000). Exposure to cadmium chloride is believed to elevate the frequency of lung tumors (Donkin et al., 2000). Our estimation of Cd shows a level similar to the typical observation in the environment.

Thallium is remarkably toxic to human beings (Mulkey et al., 1993; Manzo et al., 1989; Zitko, 1975). The symptoms of chronic thallium poisoning are gastroenteritis, diarrhea or constipation, vomiting, and abdominal pain (ATSDR, 1992). Our results show that the level of Tl in air can be elevated 100–1000 times higher than those typical observations in the States (ATSDR, 1992); However, its health risk seems insignificant.

Table 2. The estimated maximum concentrations (ng/m^3) of trace metals in a 40 m^3 room at AER = 0.25 or 0.

	AER = 0.25	AER = 0
Cd	14.2	36
Cr	465	1180
Co	4.1	10.5
Mn	77.6	197
Ni	329	934
Pb	14.2	36
Tl	3.3	8.3

The health effects owing to exposure of nickel compounds include dermatoses, asthma, hypertrophic rhinitis, nasal sinusitis, etc. (Costa, 2000). Nickel compounds are also classified as Group 1 carcinogens (IARC, 1990); the unit risk is determined to be 4.8 x 10^{-4} per (μg/m^3) (IRIS, 1996). The minimum risk level (MRL) for chronic-duration inhalation is suggested as 2 x 10^{-4} mg Nickel/m^3 by ATSDR (1997). The results indicate that exposure to Ni from incense smoke will significantly exceed the MRL during the winter period in Taiwan and the potential cancer risk will be 4.0 x 10^{-4}.

Coughing, expectoration, nasal irritation, sneezing, rhinorrhea, and nose-bleed are found in occupational exposure to chromium trioxide vapors (ATSDR, 1993). US EPA (1984) also derived a unit risk of 1.2 x 10^{-2} per (μg/m^3) for respiratory cancers for Cr(VI). Based on our estimate, the risk owing to Cr exposure could be as great as 1.4 x 10^{-2}, assuming the species of chromium in incense smoke is Cr(VI).

It must be noted that the incense combustion pattern described above regularly happens in Taiwan, but is not the worst-case scenario. During the religious or traditional holidays, for example Chinese New Year, one may burn up to a hundred times as much as regularly. Results clearly indicate that daily worship with incense burning would put people at great risk of toxic exposure to metals such as Cr and Ni. This paper calls for a detailed exposure and health risk assessment of toxic metals and their chemical species, relating to worship behavior, in order to protect the public health.

REFERENCES

ATSDR (1997) Agency for Toxic Substances and Disease Registry. Toxicological profile for nickel, p11. Atlanta, Georgia.

ATSDR (1993) Agency for Toxic Substances and Disease Registry. Toxicological profile for chromium, p7. Atlanta, Georgia.
ATSDR (1992) Agency for Toxic Substances and Disease Registry. Toxicological profile for thallium, p61. Atlanta, Georgia.
Chao HR, Lin TC, Hsieh JH (1997) Composition and characteristic of PAH emissions from Taiwanese temples. J Aerosol Sci 28(Suppl. 1): S303-S304.
Chen CJ, Wang YF, Shieh T, Chen JY, Liu MY (1987) Multifactorial etiology of nasopharyngeal carcinoma. Head and Neck Oncology Research Conference 10-12: 469-476.
Chen CJ, Wu HS, Chang AS, Luh KT, Chao HH, Chen KY, Chen SG, Lai GM, Huang HH, Lee HH (1990) Epidemiology characterics and multiple risk factors of lung cancer in Taiwan. Anticancer Res. 10: 971-976.
Costa M (2000) Trace elements: aluminum, arsenic, cadmium, and nickel. In "*Environmental Toxicants-Human exposures and their health effects*" 2nd Ed. Edited by Lippmann M. John Wiley & Sons, Inc. New York. P811-850.
Donkin SG, Ohlson DL, Teaf CM (2000) Properties and effects of metals. In "*Principles of Toxicology*", 2nd Ed, Edited. By Williams PL, James RC, and Roberts SM. John Wiley & Sons, Inc., New York. P325-344.
Kao MC, Lung SH (2000) Personal particulate exposures in Buddhist temples. Chinese J Pub Health 19: 138-143 (In Chinese, English Abstract).
IARC (1990) IARC monographs on the evaluation of carcinogenic risks to humans. Volume 49: Chromium, nickel and welding. Lyon, France: International Agency for Research on Cancer, World Health Organization. 257-445.
IPCS (1995) Environmental health criteria 165: inorganic lead. International program on chemical safety. Geneva: World Health Organization.
IRIS (1996) Integrated Risk Information System. Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office, U.S. Environmental Protection Agency, Cincinnati, OH.
Fergusson JE (1990) The heavy elements. Pergamon Press, Oxford.
Kao MC, Lung SH, (2000) Distribution of PM_{10} concentration from incense nurning under different ventilation; indoor study. Chinese J Pub Health 19: 214-220 (In Chinese, English Abstract).
Krause JD (1999) Chazacterization of scented candle emissions and associated public health risks. MS thesis, University of South Florida, Tampa, Florida.
Lau C, Fiedler H, Hutzinger O, Schwind KH, Hosseinpour J (1997) Levels of selected organic compounds in materials for candle production and human exposure to candle emissions. Chemosphere 34: 1623-1630.
Lee RS, Lin JM (1996) Gaseous aliphatic aldehydes in smoke from burning raw material of Chinese joss sticks. Bull Environ Contam Toxicol 57: 361-366.
Li CS, Lin WH, Jeng FT (1994) Characterization of outdoor submicron particles and selected combustion sources of indoor particles. Atmospheric Environment 27: 413-424.

Lin TS, Shen FM, Chen JL, Yang MH (2003) Trace metals in candle smokes. Bull Environ Contam Toxicol 70:182-187.
Lin JM, Lee JK (1998) Vaporous and particulate-bound polycyclic aromatic hydrocarbons in Chinese smoke. Toxicological and Environmental Chemistry 67: 105-113.
Lin JM, Tang CS (1994) Characterization and aliphatic aldehyde content of particulates in Chinese incense smoke. Bull Environ Contam Toxicol 53: 895-901.
Lin JM, Wang LH (1994) Gaseous aliphatic aldehydes in Chinese incense smoke. Bull Environ Contam Toxicol 53: 374-381.
Lin PH (1997) Religious change in contemporary Taiwan. Doctoral Dissertation, National Taiwan University, Taiwan.
Lin TC, Chang FH, Hsieh JH, Chao HR, Chao MR (2001) Environmental exposure to polycyclic aromatic hydrocarbons and total suspended particulates in a Taiwanese temple. Bull Environ Contam Toxicol 67: 332-338.
Lung SC, Su SM, Hu SC, (2001) Risk assessment of temple workers exposed to polycyclic aromatic hydrocarbons. Proceedings of (2001) Occupational Health Conference, Taipei, Taiwan. May 18-19. p75-76.
Manzo L, Sabbion E (1989) Thallium. In: Seiler HG, Sigel H (ed) Handbook on Toxicity of Inorganic Compounds, Chapter 62 Marcel Dekker Inc., New York
Mulkey JP, Oehme W (1993) A review of thallium toxicity. Vet. Hum. Toxicol. 35: 445-453.
NIOSH Manual of Analytical Methods (1994) Methods 7600: Chromium hexvalent, U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, Cincinnati, OH.
Nriagu JO, Kim MJ (2000) Emissions of lead and zinc from candles with metal-core wicks. Sci Total Environ 250: 37-41.
Philip M, Cass GR, Simoneit BRT (1999) Characterization of fine particle emission from burning church candles. Environ Sci Technol 33: 2352-2362.
Schoenotol R, Gibbard S (1967) Carcinogens in Chinese incense smoke (letter). Nature 216: 612.
Stumph JM, Blehm KD, Buchan RM, Gunter BJ (1986) Characterization of particleboard aerosol – size distribution and formaldehyde content. Am Ind Hyg Assoc J 47: 725-730.
Traynor CW, Apte MG, Carruthers AR, Dillworth JF, Grimsrud DT, Gundel LA (1987) Indoor air pollution due to emissions from wood-burning stoves. Environ Sci Technol 21: 691-697.
Tu KW, Knutson EO (1988) Indoor outdoor aerosol measurements for two residential buildings in New Jersey. Aerosol Sci Technol 9: 71-82.
US EPA (1984) Health assessment document for chromium. EPA 600/8-83-014F. Research Triangle Park, North Carolina.
US EPA (1998) Risk analysis to support standards for lead in paint, dust and soil. Volume I. EPA-747-R-97-006. Research Triangle Park, North

Carolina.
US EPA (2001) Candles and incense as potential sources of indoor air pollution: market analysis and literature review. EPA-600/R-01-001. Research Triangle Park, North Carolina.
Van Alphen M (1999) Emission testing and inhalational exposure-based risk assessment for candles having Pb metal wick cores. Sci Total Environ 243/244: 53-65.
Yu MC, Garabrant DH, Huang, TB, Henderson BE (1990) Occupational and other nondietary risk factors for nasopharyngeal carcinoma in Guanzhou. China Int J Cancer 45: 1033-1039.
Zitko V (1975) Toxicity and pollution potential of thallium. Sci Total Environ 4: 185-192.