Health Risk Assessment of Workers Exposed to Metals from an Aluminium Production Plant

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Objective: *Foundry is an industry involved various kinds of metals and chemicals. Workers who work in foundry industry are at risk of exposure to these metals and chemicals. Objective of this study was to conduct quantitative health risk assessment for workers who exposed to metals from an aluminium production industry.*

Material and Method: *The U.S. National Academy of Sciences' four steps of health risk assessment were used to conduct quantitative health risk assessment in this study.*

Results: *This study showed that there were 6 types of metals involved in the aluminium foundry in this study. These metals could cause various health effects but not cancers. Workers were mostly exposed to these metals by inhalation. Calculated reference dose (RfD) for inhalation of aluminium used in this assessment was 0.000015 mg/kg/day. Calculated RfD for inhalation of manganese used in this assessment was 0.000002 mg/kg/day. Calculated RfD for inhalation of copper used in this assessment was 0.000028 mg/kg/day. Calculated RfD for inhalation of zinc used in this assessment was 0.000083 mg/kg/day. Calculated RfD for inhalation of magnesium used in this assessment was 0.949833 mg/kg/day. Calculated RfD for inhalation of iron used in this assessment was 10.6219 mg/kg/day. Maximum daily doses (MDDs) for workers who exposed to metals measured in this foundry were 0, 0, 0.000463, 0.0000927, 0.000162 and 0 mg/kg/day for manganese, zinc, aluminium, iron, magnesium and copper, respectively. Finally, risk characterization for workers exposed to metals in this aluminium foundry showed that workers in this foundry had 31 times higher risk of developing diseases from aluminium than persons who were not exposed to aluminium. These workers had the same risk of developing diseases from other metals and chemicals as persons who were not exposed to those metals and chemicals.*

Conclusion: *Workers who exposed to aluminium in this aluminium production plant had 31 times risk of developing non-carcinogenic effects from aluminium compared with normal persons. Therefore, appropriate preventive measures should be applied to protect workers.*

Keywords*: Risk assessment, Aluminium, Exposure assessment*

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Foundry is an industry involved various kinds of metals and chemicals. An aluminium production plant is one of industries involve in foundry process. Workers who work in an aluminium production plant are at risk of exposure to various kinds of metals and chemicals. Objective of this study was to conduct quantitative health risk assessment for workers who exposed to metals in an aluminium production plant.

Material and Method

An aluminium production plant was selected into this study. The four steps of risk assessment proposed by the National Academy of Sciences/ National Research Council (NAS/NRC) were followed. Hazard identification was done from review articles regarding non-carcinogenic and carcinogenic effects of metals and chemicals used in this aluminium plant. Dose-response assessment was done by reviewing NOAEL/LOAEL data for non-carcinogenic effects (to derive acceptable daily intake) and unit cancer risk for carcinogenic effect from both human and animal studies. Exposure assessment was done from using air sampling data at this plant to calculate maximum daily dose (MDD) for non-carcinogenic effect and lifetime average daily dose (LADD) for carcinogenic effect. Integrating data from all three aforementioned steps led to the last step, risk characterization, to get quantitative risk estimates of metals and chemicals used

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in this aluminium production plant. Non-carcinogenic risk was calculated by comparing maximum daily dose with acceptable daily intake. Carcinogenic risk was calculated by multiplying unit cancer risk to lifetime average daily dose.

Results

Hazard identification

Metals used in this aluminium production plant were included aluminium, manganese, copper, zinc, magnesium, and iron. Health effects from aluminium exposure were respiratory system, nervous system, bones, hematological system, cardiovascular system, skeletal muscles, hepatic system, renal system, endocrine system, skin, eyes, and body weight. Copper could cause health effects on respiratory, gastrointestinal, immunological, and hematological systems. Manganese could cause health effects on respiratory system, nervous system, hematological system, immune system, development, cardiovascular system, hepatic system, renal system, endocrine system, reproductive system, and body weight. Zinc could have health effects on respiratory and hematological systems. Magnesium could cause respiratory health effects. Iron could cause health effects on respiratory system, gastrointestinal tracts, skin, and tissues. These metals were not carcinogens. Workers were mostly exposed to these metals by inhalation fumes from heat during foundry process[1,2].

Dose-response assessment

Estimation of reference concentration (RfC)

Estimation of RfC for non-carcinogenic effects of metals used in this aluminium production plant was performed by applying uncertainty factor (UF) to LOAEL or NOAEL. Uncertainty factor was used depending on type of study and type of LOAEL or NOAEL as shown in Table 1.

Reference concentration (RfC) for metals workers exposed by inhalation was estimated by using the following formula:

RfC = NOAEL or LOAEL/(UF x MF)

where NOAEL or LOAEL = value from animal or human study

UF (Uncertainty factor) = number from Table 1 above

MF (Modifying factor) = hypothetical number for quality of scientific data; 1 was used in this study for good quality of data

Reason of this study was to protect health of workers in this aluminium production plant so the lowest RfC was used in this study for conservative point of view. The lowest RfCs for acute/subacute and chronic exposure to 6 metals in this aluminium production plant were shown in Table 2.

Reference dose was derived from reference concentration by using the following formula:

$$RfD = \frac{RfC \times I}{BW}$$

where RfC = Reference concentration (mg/m^3)

I = air volume workers breathed in during whole work period = 13.9 m^3/day (29 l/min x 60 min/hr x 8 hr/day x 10^{-3} m^3/l)

BW = body weight = 60 kg (assume for Thai male workers)

Estimated reference dose for all 6 metals used in this aluminium plant were shown in Table 2.

Assumption for dose-response assessment

1. Uncertainty factors used in this study were arbitrary.

2. All data used in this study came from all

Table 1. Uncertainty factor (UF) used to estimate RfC of metals in this study

Type of LOAEL/NOAEL	Study type	Uncertainty factor (UF)
LOAEL	Animal study	1,000 (10 for LOAEL, 10 for animal study and 10 for protection of sensitive population)
NOAEL	Animal study	100 (10 for animal study and 10 for protection of sensitive population)
LOAEL	Human study	100 (10 for LOAEL and 10 for protection of sensitive population)
NOAEL	Human study	10 (10 for protection of sensitive population)

Table 2. RfC values and Estimated RfD for workers exposed to metals by inhalation in the aluminium production plant

Metals	Exposure type	RfC (mg/m^3)	RfD (mg/kg/day)	References
Aluminium	Acute and subacute	0.00061	0.000141	(3)
Aluminium	Chronic	0.000065	0.000015	(4)
Manganese	Acute and subacute	0.000009	0.000002	(5)
Manganese	Chronic	0.00032	0.000074	(6)
Copper	Acute and subacute	0.00012	0.000028	(7)
Copper	Chronic	0.0064	0.001482	(8)
Zinc	Acute and subacute	0.00036	0.000083	(9)
Magnesium	Acute and subacute	4.1	0.949833	(10)
Iron	Chronic	45.85	10.6219	(11)

Table 3. Concentration of metals sampling from cast house: remelt furnace (burner) and calculated maximum daily dose (MDD) for workers exposed to metals

Metals	Cast House: Remelt Furnace (Burner) concentration (mg/m^3)	Date of Air sampling	Calculated Maximum daily dose (MDD)(mg/kg/day)
Aluminium	0.002	July 14, 2009	0.000463
Manganese	Non-detectable (< 0.0001 mg/m^3)	June 18, 2009	0
Copper	Non-detectable (< 0.0001 mg/m^3)	August 20, 2009	0
Zinc	Non-detectable (< 0.025 mg/m^3)	June 18, 2009	0
Magnesium	0.0007	July 23, 2009	0.000162
Iron	0.0004	July 14, 2009	0.0000927

available human and animal study. Quality of these researches was not determined.

Exposure assessment

Exposure data for workers exposed to metals in this aluminium plant were from air sampling data at remelt furnace (burner) in the cast house of this plant. Air sampling pump and filters were used to collect metals. Air sampling pump rate was 2.0 l/min. Collection time was 240 minutes for each metal. Analytical method was Flame AAS/OSHA ID 121 (Table 3).

Exposure assessment for workers exposed to metals in this plant was performed for only non-carinogenic effect because none of these metals was carcinogens. Maximum daily dose (MDD) was used for exposure assessment of non-carcinogenic effects. Estimation of MDD was done by the following formula:

$$MDD = \frac{C \times I}{BW} \quad (12)$$

where C = concentration of metals at cast house: remelt furnace (burner) (mg/m^3)

I = air volume workers breathed in during whole work period = 13.9 m^3/day (29 l/min x 60 min/hr x 8 hr/day x 10^{-3} m^3/l)

BW = body weight = 60 kg (assume for Thai male workers)

Estimated maximum daily doses for all 6 metals used in this aluminium plant were shown in Table 3.

Assumption for exposure assessment

1. Exposure data in this study only came from one air sampling due to limitation of budget.

2. Assumption of ingestion and inhalation rates for calculation.

3. Assumption of body weight-use only male adult weight in calculation.

4. Exposure route used in this study was only by inhalation.

Risk characterization

Risk characterization for non-carcinogenic effect of metals used in this aluminium plant was estimated by the following formula:

Non-cancer risk = MDD/RfD

where MDD = Maximum daily dose

RfD = Reference dose (same as ADI or Acceptable daily intake)

if ≤ 1 = no risk of non-carcinogenic effects from metals

> 1 = had risk of non-carcinogenic effects from metals

To protect health of workers in this aluminium production plant, the lowest RfD was used in this study for conservative point of view. The lowest RfDs for workers exposed to 6 metals in this aluminium production plant were shown in Table 4.

By comparing maximum daily dose of each metal with its reference dose, non-cancer risk for workers exposed to each metal was estimated. (Table 5) Workers who exposed to aluminium in this aluminium production plant had 31 times risk of developing non-carcinogenic effects from aluminium compared with normal persons. For other metals, workers had no risk of developing non-carcinogenic effects from those metals compared with normal persons. (Table 5)

Assumption for risk characterization

1. Based on assumption of dose-response and exposure assessment.

Table 4. Selected RfD for workers exposed to metals by inhalation in the aluminium production plant

Metals	RfD (mg/kg/day)	References
Aluminium	0.000015	(4)
Manganese	0.000002	(5)
Copper	0.000028	(7)
Zinc	0.000083	(9)
Magnesium	0.949833	(10)
Iron	10.6219	(11)

Table 5. Non-cancer risk estimated for workers exposed to metals in the aluminium production plant

Metals	Estimated MDD (mg/kg/day)	Estimated non-cancer risk
Aluminium	0.000463	0.000463/0.000015 = 30.87
Manganese	0	0.000002 = 0
Copper	0	0/0.000028 = 0
Zinc	0	0/0.000083 = 0
Magnesium	0.000162	0.000162/0.949833 = 0.000171
Iron	0.0000927	0.0000927/10.6219 = 0.000009

2. Assume that the major route of exposure was only by inhalation.

3. Assume that a worker only exposed to each metal at a time.

4. Assume that there were no additive and synergistic effects from exposure to different metals at the same time.

Conclusion

Metals and chemicals used in this aluminium production plant were included aluminium, manganese, copper, zinc, magnesium, and iron. RfCs of aluminium by inhalation were 0.00061 mg/m^3 for acute and subacute exposure and 0.000065 mg/m^3 for chronic exposure. RfCs of manganese by inhalation were 0.000009 mg/m^3 for acute and subacute exposure and 0.00032 mg/m^3 for chronic exposure. RfCs of copper by inhalation were 0.00012 mg/m^3 for acute and subacute exposure and 0.0064 mg/m^3 for chronic exposure. RfC of zinc by inhalation was 0.00036 mg/m^3 for acute and subacute exposure. RfC of magnesium by inhalation was 4.1 mg/m^3 for acute and subacute exposure. RfC of iron by inhalation was 45.85 mg/m^3 for chronic exposure. MDDs for workers exposed to metals in this aluminium production plant were 0, 0, 0.000463, 0.0000927, 0.000162, and 0 mg/kg/day for manganese, zinc, aluminium, iron, magnesium, and copper, respectively. Workers who exposed to aluminium in this aluminium production plant had 31 times risk of developing non-carcinogenic effects from aluminium compared with normal persons. For other metals, workers had no risk of developing non-carcinogenic effects from those metals compared with normal persons.

Only 2 studies were found to conduct quantitative risk assessment. First study was human health risk assessment of an abandoned metal smelter site in Poland. Cadmium, copper, iron, manganese, lead, and zinc were proposed as the contaminants at this site. This study showed that combined hazard index for all metals was 3.1E+00 for the future industrial use and 3.2E+00 for the future recreational use. Regarding potential carcinogenic risks associated with the inhalation route, only cadmium was a contributor, with risks of 1.6E-06 and 2.6E-07 for future industrial and recreational use, respectively[13]. Another study was the assessments of releases from copper smelters and refineries and from zinc plants in Canada. Airborne levels in the vicinity of these metal-processing operations overlapped those associated with cardiorespiratory effects for PM_{10} and exceeded health-based guidelines for SO_2 and, near some facilities, lead[14].

Limitation of this study was dependent on assumption use in each step of health risk assessment. Also, there was no consideration of non-occupational exposure of metals and individual factors (such as age, body size, respiratory rate, working distance from burner). This study focused on protection of workers' health so data used in this study were conservative. Estimated risk data were the highest risk workers would have from exposure to metals in this aluminium production plant. This study showed that even aluminium level in workplace was below the threshold limit value, workers still had risk of developing non-carcinogenic effects 31 times of general persons. Therefore, other preventive measures should be applied to protect workers.

Acknowledgments

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การประเมินความเสี่ยงต่อสุขภาพพนักงานภายในโรงงานอุตสาหกรรมหลอมอะลูมิเนียม

สุรศักดิ์ บูรณตรีเวทย์

***วัตถุประสงค์**: โรงงานหลอมโลหะเป็นอุตสาหกรรมที่เกี่ยวข้องกับโลหะและสารเคมีหลายชนิด ทำให้ผู้ที่ทำงานในโรงงานมีโอกาสสัมผัสโลหะและสารเคมีดังกล่าว การศึกษานี้จึงต้องการประเมินความเสี่ยงเชิงปริมาณต่อสุขภาพของผู้ที่ทำงานในโรงงานจากการสัมผัสโลหะและสารเคมีในกระบวนการหลอมโลหะ*

***วัสดุและวิธีการ**: ดำเนินการในโรงงานหลอมอะลูมิเนียม โดยอาศัยการใช้แบบจำลองการประเมินความเสี่ยงต่อสุขภาพ 4 ขั้นตอนของ U.S. National Academy of Sciences*

***ผลการศึกษา**: โรงงานหลอมอะลูมิเนียมที่ศึกษามีโลหะที่เกี่ยวข้อง คือ อะลูมิเนียม แมงกานีส ทองแดง สังกะสี แมกนีเซียม และเหล็ก โลหะทั้ง 6 ชนิดส่งผลต่อสุขภาพหลากหลายระบบแต่ไม่ได้เป็นสารก่อมะเร็ง โดยผู้ที่ทำงานในโรงงานดังกล่าวมีโอกาสสัมผัสโลหะทั้ง 6 ชนิด ส่วนใหญ่ทางการหายใจ ค่า RfD สำหรับอะลูมิเนียมทางการหายใจที่คำนวณได้และใช้ในการศึกษานี้เป็น 0.000015 มก./กก./วัน ค่า RfD สำหรับแมงกานีสทางการหายใจที่คำนวณได้และใช้ในการศึกษานี้เป็น 0.000002 มก./กก./วัน ค่า RfD สำหรับทองแดงทางการหายใจที่คำนวณได้ และใช้ในการศึกษานี้เป็น 0.000028 มก./กก./วัน ค่า RfD สำหรับสังกะสีทางการหายใจที่คำนวณได้ และใช้ ในการศึกษานี้เป็น 0.000083 มก./กก./วัน ค่า RfD สำหรับแมกนีเซียมทางการหายใจที่คำนวณได้ และใช้ในการศึกษานี้เป็น 0.949833 มก./กก./วัน ค่า RfD สำหรับเหล็กทางการหายใจที่คำนวณได้ และใช้ในการศึกษานี้เป็น 10.6219 มก./กก./วัน ค่า MDD สำหรับผู้ที่ทำงานในโรงงานจากการตรวจวัดสารเคมีในโรงงานเป็น 0, 0, 0.000463, 0.0000927, 0.000162 และ 0 มก./กก./วัน สำหรับแมงกานีส สังกะสี อะลูมิเนียม เหล็ก แมกนีเซียม และทองแดง ตามลำดับ และจากการคำนวณประเมินความเสี่ยงต่อการเกิดโรคที่ไม่ใช่มะเร็ง พบว่ากลุ่มผู้ที่ทำงานในโรงงานหลอมอะลูมิเนียมที่ได้รับอะลูมิเนียมทางการหายใจจากการศึกษานี้มีความเสี่ยงต่อการเกิดโรคที่ไม่ใช่มะเร็ง โดยมีความเสี่ยงมากกว่าคนทั่วไป 31 เท่า สำหรับแมงกานีส สังกะสี เหล็ก แมกนีเซียม และทองแดง พบว่ากลุ่มผู้ที่ทำงานในโรงงานหลอมอะลูมิเนียมแห่งนี้ไม่มีความเสี่ยงต่อการเกิดโรคที่ไม่ใช่มะเร็ง*

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