J Occup Health 2018; 60: 263-270

Journal of Occupational Health

Brief Report

Control banding assessment of workers' exposure to indium and its compounds in 13 Japanese indium plants

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Abstract: Objectives: This study aimed to assess workers' exposure to indium and its compounds in 55 indium-handling operations among 13 Japanese plants. The surveyed plants were selected from indium-manufacturing plants whose annual indium production exceeded 500 kg. **Methods:** The Control of Substances Hazardous to Health (COSHH) Essentials control banding toolkit, which contains simple scales for hazard levels, quantities in daily use, and "dustiness" characteristics, was used to assess generic risks of indium-handling operations. The operations were then classified into one of four Control Approaches (CAs). **Results:** There were 35 indium-handling operations classified into CA4 (requires expert advice) and 16 grouped into CA3 (requires containment). There were three operations classified into CA2 (requires engineering controls) and only one into CA1 (requires good general ventilation (GV) and working practices). Of the 51 operations classified as CA4 and CA3, 36 were found to be improperly equipped with local exhaust ventilation, and the remaining 15 operations solely relied on GV practices. Respiratory protective equipment (RPE) used in the 13 indium plants was examined with reference to the recommendations of the COSHH Essentials and Japan's Technical Guidelines. **Conclusions:** Our findings suggest that stringent engineering control measures and respiratory protection from indium dust are needed to improve indium-handling operations. Our results show that the most common control approach for Japanese indium-handling operations is to require expert advice, including worker health checks for respiratory diseases and exposure measurement by air sampling.

(J Occup Health 2018; 60: 263-270)
doi: 10.1539/joh.2017-0261-BR

Key words: Control banding, COSHH Essentials, Dust, Generic risk assessment, Indium, Indium Tin Oxide

Introduction

Following the reported death of a Japanese worker who handled indium tin oxide (ITO) in an indium plant of bilateral pneumothorax in 2001[1)], poorly soluble indium compounds have been implicated in seven cases of interstitial pneumonia in Japan, two cases of pulmonary alveolar proteinosis (PAP) in the USA, and one case of PAP in China[2)]. The Japanese Ministry of Labour, Health and Welfare (MLHW) issued Technical Guidelines[3)] for the measurement of respirable indium dust in work-environment assessments, and established a target concentration of respirable dust as 0.01 mg indium (In)/m^3, with an acceptable concentration of 3×10^{-4} mg In/m^3. Miyauchi et al. (2012)[4)] demonstrated that almost all of the indium-handling workplaces in an indium-recycling company were classified into control class III, indicating that the unit work area was judged as being inappropriately controlled, and required immediate actions to improve the work environment. They also reported that according to the new MLHW's Technical Guidelines[3)], the workplace classified into control class I, indicating appropriately

Received September 27, 2017; Accepted January 27, 2018
Published online in J-STAGE March 20, 2018
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controlled, would be unable to achieve an appropriately controlled designation solely by installing a local exhaust ventilation system (LEV).

The Control of Substances Hazardous to Health (COSHH) Essentials control banding toolkit[5] is a useful tool for comparing the generic risks of indium-handling operations among Japanese plants and assessing the quality of the existing work environment with simple scales of 1) hazard levels, 2) the quantity in daily use, and 3) airborne "dustiness" characteristics of indium in the workplace. The present study was intended to assess the generic risks of indium-handling operations among Japanese indium plants according to the COSHH Essentials standards. This survey was conducted with the help of the Investigation Committee on Workers' Exposure to Indium and its Compounds, which was organized by the Japanese Industrial Safety and Health Association (JISHA).

Materials and Methods

The present study was intended to evaluate workers' exposure to indium and its compounds in 55 indium-handling operations among Japanese indium plants using the COSHH Essentials standards[5]. Thirteen of the 38 indium plants in Japan whose annual production of indium exceeded 500 kg in 2009 were selected for survey. A questionnaire of seven items was delivered to each company by mail. As shown in Table 1, these items included indium-handling operations, the relevant indium compounds and their products, the forms of indium materials, the "dustiness" of the air in areas where indium is handled, the quantity of indium materials in daily use, and engineering control measures such as LEV and personal protective equipment such as respiratory protective equipment (RPE) used in indium-handling operations. Participating companies sent the questionnaire back by mail. The amount of indium material in daily use was categorized into one of three groups: "small: grams", "medium: kilograms" and "large: tonnes". Simple descriptors put airborne solid substances into a low, medium or high dustiness band. For example, indium which does not become suspended in the air was represented as "low dustiness: pellets do not break up". Indium which can become airborne but easily sediments was represented as "Medium dustiness: granular or crystalline state", and indium which is suspended in the air for an extended period of time was represented as "High dustiness: fine solids and light powder". Fine particulates were defined as smaller in diameter than fine powder. These subjective descriptors of dustiness were re-examined by an occupational hygienist enrolled in this study. The health hazards of indium compounds were allocated into one of five Hazard Levels, from A to E, as well as Hazard Level S, based on the toxicological classification and labelling under the CLP-GHS (Globally Harmonized System)[5], with reference to the safety data sheets (SDSs) issued by the Inter-Ministerial Committee on the GHS of the Japanese Government (NITE, 2015)[6] or supplied by the indium manufacturers[7]. Carcinogenic classifications of hazardous substances published by the International Agency for Research on Cancer (IARC)[8], the Japanese Society for Occupational Health (JSOH)[9], and the American Conference of Governmental Industrial Hygienists (ACGIH)[10] were also cited.

According to the COSHH Essentials[5], Exposure Predictor (EP) bands were allocated into one of four bands, based on the relationship between the dustiness of the workplace air and the amount in daily use. "Low" and "medium" dustiness with daily use at "grams levels" were scored as EP1, "low" dustiness with daily use at "kilograms" and "tonnes" levels were scored as EP2, "medium" and "high" dustiness with daily use at the "kilograms" level were scored as EP3, and "medium" and "high" dustiness with daily use at the "tonnes" level were scored as EP4. The indium-handling operations were finally categorized into one of four generic Control Approaches (CAs) needed for adequate safety control measures. CA1 is defined as requiring "good working practices and general ventilation (GV) having a relative efficacy of 1", CA2 as requiring "engineering controls such as LEV to allow a 10-fold reduction in exposure", CA3 as requiring "containment and full enclosures having a 100-fold reduction in exposure", and CA4 as requiring "expert advice to select appropriate control measures". CAs depended on both the assigned EP band and Hazard Level.

Results

Table 1 shows the generic risk assessment of workers' exposure to indium and its compounds in 55 indium-handling operations among 13 indium plants by the COSHH Essentials[5]. Five different kinds of indium compound were handled in the 13 plants. Indium tin oxide (ITO), indium, and indium oxide were grouped into Hazard Level D due to their GHS Category 1 ratings for specific organ toxicity (repeated exposure)[6]. Indium phosphide was grouped into Hazard Level E based on its GHS Category 1 ranking for carcinogenicity[6]. Indium nitrate was grouped into Hazard Level C & S[7] based on its GHS Category 3 ratings for specific organ toxicity (single exposure) and GHS Category 2A and 2 ratings for damage to the eyes and skin, respectively.

The 55 indium-handling operations were categorized into four different CAs, depending on the stringency of appropriate control measures.

CA4

Based on both Hazard Level D or E and Exposure Predictor EP3 or EP4 ratings, the majority (64%) of total op-

Table 1. Generic risk assessment of workers' exposure to indium and its compounds in indium-handling operations among 13 Japanese plants by the COSHH Essentials.

Plant	Industry sector	Indium-manufacturing processes	Indium compound treated	GHS Hazard group	Form of indium material	Dustiness	Quantity of indium materials used daily	Exposure Prediction (EP) band	Control approach (Type)	Engineering control method in use	RPE in use
A	Recycling/ reclamation	Manufacturing metallic indium	Indium tin oxide	D	Powder	High	1,600 kg	EP4	CA4 (Expert advice)	LEV*	PAPR*
		Manufacturing indium oxide	Indium oxide	D	Powder	High	1,600 kg	EP4	CA4 (Expert advice)	LEV*	RH*
B	Manufacturing electronic devices (indium tin oxide)	Solubilizing indium	Indium	D	Solid (ingot)	Low	400kg	EP2	CA3 (Containment)	GV*	RH
		Acid-leaching indium	Indium nitrate	C&S	Solid	Low	400 kg	EP2	CA2 (Engineering control)	GV*	RH
		Filling drum containers	Indium tin oxide	D	Powder	High	100 kg	EP3	CA4 (Expert advice)	LEV*	RH*
C	Manufacturing electronic devices (indium tin oxide)	Transferring ingots	Indium	D	Metallic matter	Low	18 kg	EP2	CA3 (Containment)	GV*	RH‡
		Recovery of indium hydroxide	Indium tin oxide	D	Dried pellet	Low	10 kg	EP2	CA3 (Containment)	LEV*	RH‡
		Transferring dried indium oxide to sintering process	Indium tin oxide	D	Dry pellet	Low	10 kg	EP2	CA3 (Containment)	GV*	RH‡
		Crushing raw materials containing indium	Indium tin oxide	D	Powder	High	10 kg	EP3	CA4 (Expert advice)	LEV*	RH‡
		Weighing and bagging	Indium tin oxide	D	Powder	High	10 kg	EP3	CA4 (Expert advice)	LEV*	RH‡
D	Manufacturing electronic devices (electrode, panel)	Formulating indium	Indium	D	Solid (powder)	High	150 kg	EP3	CA4 (Expert advice)	LEV*	DH*
		Forming indium	Indium tin oxide	D	Solid (ingot)	Low	75 kg	EP3	CA4 (Expert advice)	LEV*	DH
		Processing	Indium tin oxide	D	Solid	Low	40 kg	EP2	CA3 (Containment)	LEV*	RH
		Bonding	Indium tin oxide	D	Solid	Low	630 kg	EP2	CA3 (Containment)	GV*	None*
		Finishing and shipping	Indium tin oxide	D	Solid (powder)	High	25 kg	EP3	CA4 (Expert advice)	LEV*	RH*
E	Manufacturing electronic devices (electrode, panel)	Leaching	Indium	D	Powder	High	600 kg	EP3	CA4 (Expert advice)	LEV*	DH*
		Sintering	Indium oxide	D	Fine powder	High	125 g	EP2	CA3 (Containment)	LEV*	RH*
		Filling and packaging	Indium	D	Fine powder	High	700 kg	EP3	CA4 (Expert advice)	LEV*	RH*
		Electrolysis process	Indium	D	Crystalline	Medium	500 kg	EP3	CA4 (Expert advice)	GV*	RH*
		Wetting process	Indium	D	Particulate	Medium	100 kg	EP3	CA4 (Expert advice)	GV*	RH*
		Shot-brusting	Indium	D	Fine powder	High	960 kg	EP3	CA4 (Expert advice)	Containment*	RH*
		Leaching raw materials	Indium	D	Solid	Low	3,000 kg	EP2	CA3 (Containment)	GV*	RH
		Leaching and casting	Indium	D	Fine particulate	High	40 kg	EP3	CA4 (Expert advice)	GV*	RH*

Table 1. (continued)

Plant	Industry sector	Indium-manufacturing processes	Indium compound treated	GHS Hazard group	Form of indium material	Dustiness	Quantity of indium materials used daily	Exposure Prediction (EP) band	Control approach (Type)	Engineering control method in use	RPE in use
F	Manufacturing electronic devices (sputtering target)	Confirmation	Indium tin oxide	D	Solid flake	Medium	140 kg	EP3	CA4 (Expert advice)	LEV*	RH*‡
		Bagging and weighing	Indium tin oxide	D	Solid flake	Medium	140 kg	EP3	CA4 (Expert advice)	GV*	RH*‡
G	Recycling/ reclamation	Indium recovery	Indium tin oxide	D	Crushed powder	High	320 kg	EP3	CA4 (Expert advice)	LEV*	RH*
		Casting indium ingots	Indium tin oxide	D	Fine particulate	High	320 kg	EP3	CA4 (Expert advice)	LEV*	RH*
		Leaching metal indium	Indium	D	Fine particulate	Medium	680 kg	EP3	CA4 (Expert advice)	LEV*	RH*
		Filtering and drying	Indium	D	Caked indium	Low	680 kg	EP3	CA4 (Expert advice)	GV*	RH*
H	Manufacturing film	Mixing and preparing powder	Indium tin oxide	D	Powder	High	1,800 kg	EP4	CA4 (Expert advice)	LEV*	PAPR*
		Preparing powder from raw material	Indium tin oxide	D	Powder	High	700 kg	EP3	CA4 (Expert advice)	LEV*	RH*
I	Manufacturing electronic devices (sputtering target, semi-conductors, surfacing materi-als)	Transferring materials	Indium tin oxide	D	Powder	High	820 kg	EP3	CA4 (Expert advice)	LEV*	RH*
		Formulating	Indium tin oxide	D	Caked indium	Low	2,400 kg	EP2	CA3 (Containment)	LEV*	RH
		Sampling	Indium tin oxide	D	Powder	High	40 g	EP1	CA2 (Engineering control)	GV*	RH*
		Filling and packaging	Indium tin oxide	D	Caked indium	Low	2,900 kg	EP2	CA3 (Containment)	LEV*	RH
		Pulverizing	Indium tin oxide	D	Caked indium	Low	220 kg	EP2	CA3 (Containment)	LEV*	RH
		Removal and recovery	Indium phosphide	E	Caked indium	Low	35 kg	EP2	CA4 (Expert advice)	GV*	RH
		Transferring	Indium tin oxide	D	Powder	High	2,050 kg	EP4	CA4 (Expert advice)	LEV*	RH*
		Pulverizing	Indium tin oxide	D	Pellet	Low	110 g	EP1	CA1 (GV)	LEV	RH
		Cleaning after pulverizing	Indium tin oxide	D	Powder	High	20 g	EP2	CA2 (Engineering control)	GV*	RH*
		Recovery of removed material	Indium phosphide	E	Caked indium	Low	270 kg	EP2	CA4 (Expert advice)	LEV*	RH
		Drying	Indium tin oxide	D	Powder	High	134 kg	EP3	CA4 (Expert advice)	LEV*	RH*
		Wafer making	Indium tin oxide	D	Crystalline	Medium	2.5 kg	EP3	CA4 (Expert advice)	LEV*	None*

Table 1. (continued)

Plant	Industry sector	Indium-manufacturing processes	Indium compound treated	GHS Hazard group	Form of indium material	Dustiness	Quantity of indium materials used daily	Exposure Prediction (EP) band	Control approach (Type)	Engineering control method in use	RPE in use
J	Recycling/ reclamation	Pretreatment	Indium	D	Powder	Medium	130 kg	EP3	CA4 (Expert advice)	LEV*	CFA
		Reductive casting	Indium	D	Metallic matter	Low	200 kg	EP2	CA3 (Containment)	LEV*	RH (g/f)*
		Refining electrolyzed indium	Indium	D	Metallic matter	Low	200 kg	EP2	CA3 (Containment)	LEV*	RH (g/f)*
		Refining casted indium	Indium	D	Fine particulate	High	500 kg	EP3	CA4 (Expert advice)	LEV*	RH*
		Casting indium ingots	Indium	D	Metallic fume	High	500 kg	EP3	CA4 (Expert advice)	GV*	None*
		Manufacturing sheets & film	Indium	D	Metallic sheet	Low	500 kg	EP2	CA3 (Containment)	GV*	RH
K	Recycling/ reclamation	Acid leaching	Indium	D	Fine powder	High	125 kg	EP3	CA4 (Expert advice)	LEV*	GS*
		Crushing raw materials	Indium tin oxide	D	Pellet	Low	150 kg	EP2	CA3 (Containment)	LEV*	RH
		Casting indium ingots	Indium	D	Fine powder	High	150 kg	EP3	CA4 (Expert advice)	LEV*	RH*
L	Metal refining	Metal casting	Indium	D	Solid (fume)	High	6 kg	EP3	CA4 (Expert advice)	GV*	RH (g/f)*‡
M	Manufacturing solder	Transferring and leaching	Indium	D	Metallic matter	Low	500 kg	EP2	CA3 (Containment)	LEV*	RH
		Filling 18 *l* containers	Indium	D	Fine powder	High	1,000 Kg	EP4	CA4 (Expert advice)	LEV*	

Hazard Levels by GHS: D and S indicate specific organ toxicity (repeated exposure) as Category 1 and damage to eyes and skin as Category 1 or 2, respectively; while E indicates carcinogencity as Category 1B for indium phosphide.

Engineering control methods: LEV, local exhaust ventilation; GV, general ventilation

RPE, respiratory protective equipment: DH, disposable half mask; RH (g/f), reusable half mask with gas/vapour filter; PAPR, powered air-purifying respirator mask; CFA, constant flow air-line mask; GS, gas respirator half mask.

* indicates the operations where engineering control or RPE in use does not meet COSHH Essentials standards.

‡ indicates that the mask was worn only during the period when workers handled the hazardous indium compounds.

erations were found to need the most stringent control measures (CA4), which require expert advice to implement adequate control measures. Among the 35 CA4-categorized operations, the engineering control measure of containment was present in one (3%) shot-brusting operation. The remaining 26 (74%) and eight (23%) operations had LEV and GV, respectively. Workers handling Hazard Level E indium compounds were asked to wear appropriate RPE with an assigned protection factor (APF) range from 10 to 2000, depending on the amount in daily use and dustiness[6]. As shown in Table 1, a highly efficient powered air-purifying respirator mask (PAPR) was worn in two CA4-categorized operations, which handled ITO powder suspended in the air with “high dustiness” at ton levels. Of the 35 CA4-categorized operations, one used constant flow airline masks (CFA) (3%), two used PAPR (6%), 25 used reusable half masks (RH) (71%), three used disposable half masks (DH) (9%), one used RH with a gas/vapor filter (RH (g/f)) (3%), one used a gas respirator half mask (GS) (3%), and two operations had no mask (6%). RH was worn among the workers assigned to two operations handling Hazard Class E-allocated indium phosphide. Altogether, there were 28 (80%) CA4-categorized operations where workers wore masks which do not fulfill the assigned protection factor (APF) standards specified by RPE guidelines, and appropriate masks were only worn in seven CA-4 categorized operations (20%).

CA3

Sixteen operations (29%) were categorized into CA3 (containment and full enclosures), based on Hazard Level D and EP2 ratings. CA3-categorized operations are required to use the stringent control measures of containment or fully-enclosed LEV, reducing exposure by 100- and 10-fold relative to GV and engineering controls, respectively. LEV and GV were installed in 10 (63%) and six (38%) of the 16 CA3-cetegorized operations, respectively. Workers in CA3-categorized operations were asked to wear RPE with the range used in indium-handling operations designated as Hazard Level E. Appropriate RH fulfilling the HSE’s RPE standards[11] was worn in 12 (75%) CA3-categorized operations, while RH (6%) was misused in the remaining sintering operation instead of the recommended full face mask with APF40. RH (g/f) was also misused in the two indium-handling operations (13%) instead of RH. No mask was worn in a bonding CA3-categorized operation (6%), instead of the recommended RH.

CA2 and CA1

There were three indium-handling operations which were categorized as CA2, which requires less stringent engineering controls, and only one categorized as CA1, which simply requires good GV standards and working practices. The three CA2-categorized operations were required to replace GV with LEV equipped with a well-capturing and -receiving hood. Although ITO is a highly hazardous substance designated as Hazard Level D, in these operations workers handled only small quantities of ITO (gram levels). The indium nitrate-handling operation equipped only with GV was judged as CA2, since indium nitrate is allocated into Hazard Level C & S, based on H-statement 335 (may cause respiratory irritation) in the COSHH Essentials[5]. In addition to replacing GV with LEV, allocation of indium nitrate into Hazard Level C & S on the basis of potential damage to the skin and eyes (GHS Category 2 and 2A, respectively) indicates that appropriate personal protective equipment should be worn to protect these organs based on the COSHH’s Index Control Guidance Sheets S100 and S101[5]. Only one indium-handling operation was judged to have adequate control of GV (CA1), and as having good working practices. Masks fulfilling HSE’s RPE standards[15] were worn in two of the four CA1- and CA2-categorized operations, while RH was used in the other two operations (sampling and cleaning ITO after pulverizing), instead of full face masks with APF40.

Discussion

Using the COSHH Essentials[5], this study revealed that 51/55 (93%) of indium-handling operations in 13 Japanese plants were allocated into the control categories of CA4 (requiring expert advice) and CA3 (requiring containment), and thus require stringent control measures to ensure worker safety. Three operations which handled small quantities of indium were allowed to follow the less stringent CA2 control measures (engineering controls), and only one operation was categorized as CA1 (requiring good GV standards and working practices). The reason that the most stringent control measures (CA3 and CA4) are required in almost all of the indium-handling operations is due to the classification of indium compounds into Hazard Level D, based on a GHS Category 1 rating for specific organ toxicity (repeated exposure)[6], with the exception of the carcinogenic indium phosphide which was classified as Hazard Level E. Consistently, the ACGIH[10] did not classify any indium compounds as human carcinogens except for indium phosphide. On the other hand, the JSOH[9] classified poorly soluble indium compounds as Group 2A carcinogens, since various indium compounds, including ITO, indium oxide, indium nitrate, and metallic indium, can be given a GHS Category 1 rating for carcinogenicity on the basis of the H-statement in the COSHH Essentials[5]. If these poorly soluble indium compounds were allocated into Hazard Level E, 15 more CA3-categorized operations would have been re-classified as CA4 (requiring expert advice). These findings demonstrate a major shortcoming of the COSHH

Essentials, namely that conflicting hazard information can cause different safety recommendations, causing confusion and potentially placing workers at risk.

Two groups[12,13] have argued that use of the three simple scales in the COSHH Essentials may result in excessive safety control measures. Jones and Nicas[12] reported that the safety margins were much larger for the substances in Hazard Level D than for those grouped into Hazard Levels B and C. Hashimoto et al.[13] demonstrated that in comparison with comprehensive risk assessment, there were seven cases where assessments made by control banding were identified as "over-controlled", with no cases identified as "under-controlled", among eight cases requesting expert advice among 12 tasks in the petroleum industry. The present study revealed that workplace total dust concentrations exceeded the ACGIH's threshold limit value-time weighted average (TLV-TWA) value of 0.1 mg/m^3 in seven of 11 Japanese indium plants, and that there was no indium plant with a workplace concentration below 3×10^{-4} mg/m^3, the MHLW Technical Guideline's acceptable concentration of respirable dust. Thus, it appears that the safety control measures for indium-handling operations were not excessive, given the current occupational standards for indium and its compounds. These findings instead suggest that generic control banding by the COSHH Essentials is appropriately designed to secure indium-handling safety by compensating for banding-based hazard and exposure information and judiciously requesting expert intervention where appropriate.

The COSHH Essentials[5] estimate an acceptable concentration range of airborne dust[5], and state that airborne concentrations of Hazard Level D-allocated indium dust should be maintained at a range below 0.01 mg/m^3. This acceptable concentration of indium dust appears to be an excessive safety control measure judgement for the highly hazardous and non-carcinogenic indium, given the ACGIH's recommendation of a TLV-TWA of 0.1 mg/m^3 for indium and compounds without a carcinogenicity notation[10].

The COSHH Essentials[5] toolkit recommended "seek expert advice" for the majority of indium-handling operations, and specified this advice as G400 (general health check-up) and G409 (exposure measurement by air sampling). The expert is encouraged to provide employers with the latest information regarding human health effects such as the OEL, industrial hygiene control technology, and personal protective equipment. In comparison with the ACGIH's TLV-TWA of 0.1 mg In/m^3, the MLHW's Technical Guidelines[3] designated an acceptable concentration of respirable dust as 3×10^{-4} mg In/m^3. This occupational exposure standard was derived from a comprehensive risk assessment of inhalation dose-carcinogenic response relationships, using rats and mice exposed to respirable ITO dust for 2 years[14].

CA3 operations have technical difficulties implementing conventional engineering containment control measures as recommended by the COSHH Essentials[5] without disturbing the manual tasks involved in handling hazardous indium compounds. The relative efficacy of containment in comparison with GV results in a 100-fold reduction in exposure to these substances[5]. An alternative control technology such as LEV equipped with a partially-enclosed hood can be also effective. The relatively high efficacy of a partially enclosed LEV system equipped with a well-positioned capture hood can be maintained by using a capture velocity of greater than 0.7-1.0 m/sec for dust, according to the Ordinance of Industrial Safety and Health on Prevention of Hazards to Dust[15].

The finding that appropriate dust masks fulfilling the HSE's RPE standards[11] were worn in only 38% (21/55) of indium-handling operations suggests that appropriate selection of RPE is of critical importance to protect workers from excessive exposure to indium dust. According to the HSE's RPE at Work[11] and the COSHH Essentials[5], workers assigned to indium-handling operations having a "medium" amount in daily use and "medium" dustiness must wear RPE with an APF of 40, i.e. a full face mask or a full face powered mask. When the work environment is worsened to include a "large" amount in daily use and "high" dustiness, workers must wear RPE with an APF of 2000, i.e. a breathing apparatus (BA) supplying air from an independent source such as a compressed air cylinder or air compressor. Types of RPE available are positive-demand, compressed airline BA with a full face mask (BS EN 14593), and positive-demand full face masks with a self-contained BA (SCBA) (BS EN 137)[11]. Table 1 showed that among 55 indium-handling operations, there were 5 indium-manufacturing processes where workers must wear a breathing apparatus with demand valve. Employers are obligated to make sure that the RPE wearer is protected to a level below the workplace exposure limit (WEL). According to the MHLW's Technical Guidelines, workers assigned to indium-handling operations whose workplace concentration of respirable dust either "was not measured" or exceeded 0.03 mg In/m^3 must wear RPE with an APF of 100 to 1000 or higher, i.e. a powered air-purifying respirator equipped with a full face-piece and a particle capture efficiency of 99.9% or higher, a continuous flow air-line respirator equipped with a full face piece, or a pressure demand air-line respirator with full face piece and half mask. Altogether, this study indicates that safety experts should be encouraged to access more accurate and up-to-date information about appropriate RPE in consideration of the current WEL.

Conclusions

Control banding assessment using the COSHH Essentials was useful for comparing the generic risks of indium-handling operations and assessing the contamination of work environments with indium dust in Japanese indium plants. Our results revealed that the majority of indium-handling operations among 13 plants are allocated into the categories of CA4 (requires expert advice) and CA3 (requires containment) necessary for stringent engineering control measures and appropriate personal protective equipment including RPE. This finding is attributed to the highly hazardous nature of indium and its compounds, which are allocated into Hazard Levels D and E. Therefore, the COSHH Essentials were effective for generic risk assessment of workers exposed to indium dust in Japanese plants.

Acknowledgments: This survey was conducted under a research project sponsored by the Ministry of Health, Labour, and Welfare, Department of Industrial Safety and Health, Division of Chemical Hazards Control. The authors are deeply indebted to the indium plants participating in this survey, the members of the Investigation Committee, and the staff of JISHA for their cooperation and efforts throughout this study. The authors heartily thank Dr. Kazuyuki Omae, Professor Emeritus of Keio University, and Dr. Satoko Iwasawa of the National Defense Medical College for their critical editing of the manuscript.

Conflict of interest: None declared.

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