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The fate and management of high mercury-containing lamps from high technology industry

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Abstract

This study investigated the fate and management of high mercury-contained lamps, such as cold cathode fluorescent lamps (CCFLs), ultraviolet lamps (UV lamps), and super high pressure mercury lamps (SHPs), from high technology industries in Taiwan, using material flow analysis (MFA) method. Several organizations, such as Taiwan Environmental Protection Administration, Taiwan External Trade Development Council, the light sources manufactories, mercury-containing lamps importer, high technology industrial user, and waste mercury-containing lamps treatment facilities were interviewed in this study. According to this survey, the total mercury contained in CCFLs, UV lamps, and SHPs produced in Taiwan or imported from other countries was 886 kg in year 2004. Among the various lamps containing mercury, 57 kg mercury was exported as primary CCFLs, 7 kg mercury was wasted as defective CCFLs, and 820 kg mercury was used in the high technology industries, including 463 kg mercury contained in exported industrial products using CCFLs as components. On the contrary, only 59 kg of mercury was exported, including 57 kg in CCFLs and 2 kg in UV lamps. It reveals that 364 kg mercury was consumed in Taiwan during year 2004. In addition, 140 kg of the 364 kg mercury contained in lamps used by high technology industry was well treated through industrial waste treatment system. Among the waste mercury from high technology industry, 80 kg (57%), 53 kg (38%), and 7 kg (5%) of mercury were through domestic treatment, offshore treatment, and emission in air, respectively. Unfortunately, 224 kg waste mercury was not suitable treated, including 199 kg mercury contained in CCFL, which is a component of monitor for personal computer and liquid crystal display television, and 25 kg non-treated mercury. Thus, how to recover the mercury from the waste monitors is an important challenge of zero wastage policy in Taiwan.

Keywords: Cold cathode fluorescent lamp (CCFL); UV lamp; Super high pressure mercury lamp (SHP); Mercury; Material flow analysis (MFA)

1. Introduction

Mercury, which has been claimed on the priority list of 129 chemical substances by USEPA, is one of the most toxic chemicals in Earth. Mercury is the only pure metal that is a liquid at room temperature. Mercury's melting point is −39 °C, which is the lowest of all pure metals. It also has a low boiling point at 357 °C. Mercury is a persistent environmental pollutant with bioaccumulation ability in fish, animal, and human being. In the United States, it had already legislated against some mercury-containing products sales. The European Union proposed to control the mercury-containing products by the "Directive 2002/95/EC". According to the assessment report of mercury-containing products from the United Nations, Taiwan is a country with high mercury emission. Thus, to minimize, manage, and treat the mercury-containing products is an important issue worldwide, especially in Taiwan.

Although the usage of mercury was decreasing significantly in the last decade, the mercury is still an important material of industrial products, especially in various light sources. Most lamps using mercury in the fluorescent bulbs for converting electrical energy to radiant energy in the ultraviolet range and then re-radiating in the visible spectrum [1]. When the mercury-containing lamps were discarded, all the mercury releases into the environment and is harmful to the human being and other organisms.

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Since there are many kinds of commercial light sources containing mercury, three high mercury-containing lamps, including cathode fluorescent lamps (CCFLs), ultraviolet (UV) lamps, and high pressure mercury lamps (SHPs), were investigated in this study. They were used with huge quantity in Taiwan. According to the data from the manufacturers, importers, and high technology industrial users of mercury-containing lamps, they showed that the usage of CCFLs increasing rapidly in Taiwan with an increasing of advanced electronic products. The CCFLs are components of liquid crystal display television (LCD TV), LCD monitor, scanner and digital camera, etc. On the other hand, the UV lamps, such as high pressure mercury lamp, metal halide lamp, high pressure sodium vapor lamp, and high pressure xenon arc-lamp, can be applied on the industrial dryer, disinfection process for sanitation, cleaning, and plate making. Finally, the SHPs are used in the exposure processes to produce the crystalline grain of electronic components, the components of micro mechanical and electrical products, monitors, and semiconductors. Generally, the UV lamps for disinfection contain 4–60 mg mercury per lamp, while the SHPs for industrial processes contain maximum 20 g mercury per lamp. This implies that a large waste mercury-containing lamp needs to be well managed and treated to prevent the mercury vapors contamination from the cracked lamps worldwide. Thus, to understand and control the fate of mercury-containing lamps is a major issue in most countries, especially in Taiwan [2].

The material flow analysis (MFA) is a useful method and is already used to understand and control the fate of mercury-containing products in many studies. The MFA method is a tool to analyze the metabolism of social materials in order to analyze material flows and stocks within a given system, to evaluate the importance and relevance of these flows and stocks, and to control material flows and stocks in view of certain goals such as sustainable development [3]. In 2004, the Denmark EPA carried out the project "Mass Flow Analyses of Mercury 2001" by using MFA method focused on 12 mercury-containing products such as light sources, relays, thermometers, batteries, chemicals, etc., to examine the using quantity and the emission fates to air, water, soil, and incinerator residues. At that project, the mercury-containing light sources included the fluorescent tubes, energy saver lamps, mercury vapor lamps, sodium vapor lamps, metal-halide lamps, UV lamps, CCFLs, light sources in vehicles, and other discharge lamps [4]. On the other hand, the Minnesota Pollution Control Bureau in the United States carried out the project "Substance Flow Analysis of Mercury in Products" to evaluate the fates of 14 mercury-containing products, including the fluorescent light bulbs and high intensity discharge lamps, using combined MFA and Quality Assessment Method [5].

Taiwan is the second major monitor producing country in the world and waste large quantities of mercury-containing lamp such as CCFLs and SHPs every year. In order to clearly understand the fate, import quantity, waste quantity of mercury-containing lamps and waste mercury, this study interviewed several institutes related to mercury-containing lamps, such as Taiwan Environmental Protection Administration (Taiwan EPA), Taiwan External Trade Development Council (TAITRA), Bureau of Foreign Trade, Directorate General of Customs, the light sources manufacturers, mercury-containing lamps importers and exporters, high technology industrial users, and waste mercury-containing lamps treatment facilities, to evaluate the fates of CCFLs, UV lamps, and SHPs in year 2004 by using the MFA method. The results of the survey can also offer a reference for the control, management, and treatment of mercury-containing lamps from high technology industry in Taiwan.

2. Materials and methods

2.1. Material flow analysis

In this study, the MFA method was used to identify the fate of mercury-containing lamps. The MFA method is a tool which helps decision makers to understand the metabolism of a specific society or region. Briefly, the MFA method examines the materials flowing into a given system, the stocks and flows within this system and the resulting outputs from the system to other systems [3]. Four major basic steps, i.e., goal and system definition, data acquisition and inventory, material balances and modeling, and interpretation, were used and described as follows [3,5]:

(a) *Goal and system definition*: It is necessary to decide the target and the margin of time and space before using MFA method. In this study, the target is to establish the material flow system of three kinds of mercury-containing lamps, i.e., CCFLs, UV lamps, and SHPs, among the import, export, and waste in Taiwan. The time margin is year 2004 and the space margin is high technology industry in Taiwan.

(b) *Data acquisition and inventory*: In order to construct the system and confirm the stocks and flows within this system, it needs to acquire information widely, such as paper review, market research, expert judgment, best estimation, and direct interview with the manufactory, importer, exporter, and high technology industrial user of mercury-containing lamps.

(c) *Material balances and modeling*: In this step, the collected data can be used to construct the system. When some data are not acquired, the mass balance or so-called mass conservation, i.e., mass-in is equal to mass-out, can be used to balance the materials.

(d) *Interpretation*: To interpret the results of MFA analysis for mercury-containing lamps.

2.2. The estimation of mercury-containing lamps quantity

Since no standardized method is used for the descriptions of material cycling in macroscopic level, the types of material cycles in each study should be documented and the methods of their quantification need to be standardized [6,7]. In this study, the optimized results were obtained by wide data collection and calculated using the following equation [8]:

$$F_{Hg} = F_{production(2004)} + F_{import(2004)} - F_{export(2004)} + S_{(2003)} - S_{(2004)} - F_{usage(2004)} \quad (1)$$

where F is the flow; S the stock; F_{Hg} the total mercury in the system which can be the potential waste mercury; $F_{production(2004)}$

Table 1
The calculating table of mercury-containing lamps in Taiwan in year 2004

Light source	Flow	Quantity calculation
CCFLs	Production	$F1_{\text{production(2004)}}$ = quantity × concentration
	Import	$F1_{\text{import(2004)}}$ = quantity × concentration
	Export	$F1_{\text{export(2004)}}$ = quantity × concentration
	Usage for other industrial products	$F1_{\text{usage(2004)}}$ = quantity × concentration
	Waste[a]	$F1_{\text{Hg}} = F1_{\text{production(2004)}} + F1_{\text{import(2004)}} - F1_{\text{export(2004)}} - F1_{\text{usage(2004)}}$
SHPs	Production	No domestic production
	Import	$F2_{\text{import(2004)}}$ = quantity × concentration
	Export	No export
	Usage for other industrial products	No usage for other industrial products
	Waste	$F2_{\text{Hg}} = F2_{\text{import(2004)}}$
UV lamps	Production	No domestic production
	Import	$F3_{\text{import(2004)}}$ = quantity × concentration
	Export	$F3_{\text{export(2004)}}$ = quantity × concentration
	Usage for other industrial products	No usage for other industrial products
	Waste	$F3_{\text{Hg}} = F3_{\text{import(2004)}} - F3_{\text{export(2004)}}$

[a] The potential mercury waste quantity from the industrial products.

the mercury contained in the lamps, including the declaration of defective lamps ($F_{\text{declaration (2004)}}$), produced domestically in year 2004; $F_{\text{import(2004)}}$ the mercury contained in the imported lamps in year 2004; $F_{\text{export(2004)}}$ the mercury contained in the exported lamps in year 2004; $S_{(2003)}$ and $S_{(2004)}$ the mercury contained in the stock lamps in years 2003 and 2004; and $F_{\text{usage(2004)}}$ is the mercury-containing lamps as a component used for other industrial products in year 2004.

Since very few mercury-containing lamps is stocked in Taiwan according to the statistical data, the items $S_{(2003)}$ and $S_{(2004)}$ of Eq. (1) were ignored and simplified as Eq. (2).

$$F_{\text{Hg}} = F_{\text{production(2004)}} + F_{\text{import(2004)}} - F_{\text{export(2004)}} - F_{\text{usage(2004)}} \quad (2)$$

Because the CCLF is a component of monitor of PC and LCD TV, the item $F_{\text{usage(2004)}}$ would present in the mercury material flow analysis of CCFLs ($F1_{\text{Hg}}$) which is shown as Eq. (3).

$$F1_{\text{Hg}} = F1_{\text{production(2004)}} + F1_{\text{import(2004)}} - F1_{\text{export(2004)}} - F1_{\text{usage(2004)}} \quad (3)$$

where $F1_{\text{Hg}}$ is the total potential waste mercury from CCFLs; $F1_{\text{production(2004)}}$ the mercury contained in the CCFLs produced domestically in year 2004 (quantity × concentration); $F1_{\text{import(2004)}}$ the mercury contained in the imported CCFLs in year 2004 (quantity × concentration); $F1_{\text{export(2004)}}$ the mercury contained in the exported CCFLs in year 2004 (quantity × concentration); $F1_{\text{usage(2004)}}$ is the CCFLs used as a component for other industrial products in year 2004 (quantity × concentration).

In addition, according to the interviewed with the domestic manufactory, there is no SHP production and exported in Taiwan in year 2004. Besides, the SHP is not a component of other industrial products. Thus, the terms $F_{\text{production(2004)}}$, $F_{\text{export(2004)}}$, and $F_{\text{usage(2004)}}$ are all equal to zero in the mercury material flow analysis of SHPs (F_2) which is shown as Eq. (4).

$$F2_{\text{Hg}} = F2_{\text{import(2004)}} \quad (4)$$

where $F2_{\text{Hg}}$ is the total potential waste mercury from SHPs; and $F2_{\text{import(2004)}}$ is the mercury contained in the imported SHPs in year 2004 (quantity × concentration).

Finally, since there is no UV lamp production in Taiwan in year 2004 and the UV lamp is not a component of other industrial products, the terms $F_{\text{production(2004)}}$, and $F_{\text{usage(2004)}}$ are all equal to zero in the mercury material flow analysis of UV lamps (F_3) which is shown as Eq. (5). Table 1 showed the quantity analysis of CCFLs, SHPs, and UV lamps in this study.

$$F3_{\text{Hg}} = F3_{\text{import(2004)}} - F3_{\text{export(2004)}} \quad (5)$$

where $F3_{\text{Hg}}$ is the total potential waste mercury from UV lamps; $F3_{\text{import(2004)}}$ the mercury contained in the imported UV lamps in year 2004 (quantity × concentration); and $F3_{\text{export(2004)}}$ is the mercury contained in the exported UV lamps in year 2004 (quantity × concentration).

3. Results and discussions

3.1. Basic data of mercury-containing lamps

3.1.1. Import situation of primary mercury material and mercury-containing lamps

In order to identify the import situation of primary mercury material and mercury-containing lamps, this study searched the importing countries, kinds of goods, and quantity of the above importing mercury compounds in the database of the TAITRA and Bureau of Foreign Trade of Taiwan in years 2002–2004, as showed in Tables 2 and 3. It shows in Table 2 that 50.723 t of primary mercury material, including mercury (20.971 t), mercuric chloride (0.216 t), and other compounds of precious metals/amalgams of precious metals (29.536 t), was imported to Taiwan in years 2002–2004 from 17 countries. The

Table 2
Import of primary mercury material during years 2002–2004 (t)

Country	Primary mercury			
	Mercury (1)	Mercuric chloride (2)	Other compounds of precious metals/amalgams of precious metals (3)	Subtotal in individual countries (4) = (1) + (2) + (3)
Australia	–	–	0.013	0.013
Argentina	–	–	0.006	0.006
Belgium	0.025	–	0.107	0.132
China	0.035	–	4.013	4.048
France	–	–	1.101	1.101
Greece	–	–	1.010	1.01
Germany	0.012	0.004	0.646	0.662
Hong Kong	–	–	2.808	2.808
Italy	–	–	2.370	2.37
India	–	0.200	–	0.2
Japan	0.021	–	7.895	7.916
Spain	20.874	0.012	–	20.886
Switzerland	–	–	3.175	3.175
South Africa	–	–	0.110	0.11
Sweden	–	–	0.050	0.05
United States	0.004	–	6.020	6.024
UK	–	–	0.212	0.212
Total	20.971	0.216	29.536	50.723

Data source: Arranged from TAITRA and Bureau of Foreign Trade of Taiwan.

first three countries imported the most primary mercury material were Spain (20.886 t), Japan (7.916 t), and United States (6.024 t).

Furthermore, the categories and quantity of imported light sources from 2002 to 2004 was shown as Table 3. It revealed that 12 kinds of lamps, such as electrical head-lighting and tail-lighting for motor vehicles, electrical head-lighting and tail-lighting for motorcycles, lights and interior for motor vehicles, UV lamps, explosion-proof lamps, arc-lamps, metal halide lamps, sodium vapor lamps, electric mercury vapor lamps, hot cathode fluorescent lamps, numerical indicator tubes of fluorescent type, and other discharge lamps, was imported from 56 countries during 2002–2004. Table 3 shows the first 20 major imported countries, including China (9828.219 t), Japan (5340.95 t), Thailand (1852.893 t), Germany (986.956 t), and United States (805.89 t).

3.1.2. The waste situation of high mercury-containing lamps and fluorescent tubes

In Taiwan, two recovering systems of mercury-containing lamps using in high technology industries are used. The fluorescent tubes are recovered by a individual recovering system, while other mercury-containing lamps, especially high mercury-containing lamps such as SHPs and UV lamps using in the industrial processes, are recovered by industrial waste treatment system. According to our survey, 109 companies produced mercury- or fluorescent powder-containing lamps in Taiwan with a contribution of 1.6, 32.9, and 73.4 t of mercury- or fluorescent powder-containing lamps in years 2002, 2003, and 2004, respectively, which was showed in Table 4. On the other hand, 524, 7891.7, and 4363.7 t of fluorescent tubes were recovered in years 2002, 2003, and 2004, respectively.

3.2. The estimation of the fates of high mercury-containing lamps in Taiwan

Table 5 shows the estimation of the flow and quantity of CCFLs, UV lamps, and SHPs in Taiwan in year 2004. The fates of mercury compounds of mercury-containing lamps were also showed in Fig. 1. Generally, the high mercury-containing light sources used in Taiwan are either produced domestically or imported from other countries. For the CCFLs, it was reported that 132,033,300 and 351,950,100 lamps was produced domestically and imported in year 2004, respectively. This revealed that the overall input of mercury-containing light sources was 483,983,400 lamps or 726 kg mercury in year 2004. On the contrary, only 37,658,500 CCFLs, i.e., 57 kg mercury, was exported in year 2004. Furthermore, according to the data from four predominant panel manufacturers in Taiwan, it revealed that 441,491,400 CCFLs (662 kg mercury) were used as a component for other industrial products. Among these used CCFLs, 30% was used for domestic sale, while 70% was for abroad sale, as indicated in Table 6. Since 1.5 mg mercury contained in each lamp, the overall mercury containing in domestic and abroad sales were 199 and 463 kg in year 2004, respectively. This implied that 199 kg mercury might be have the potential to waste in Taiwan, and should be controlled well to prevent the environmental pollution. It also found that 4,833,300 CCFLs, with 7 kg mercury contained, were detected as defective lamps. Such defective lamps had already been treated well in the industrial waste treatment processes.

In addition, all the SHPs used in high technology industry were imported, about 25,700 lamps in year 2004, from other countries. Since the range of mercury content in SHPs is wide, it is very hard to calculate the mercury quantity by such data.

Table 3
Import of mercury-containing light sources during years 2002–2004 (t)

Country	Light source											
	Electrical head-lighting and tail-lighting for motor vehicles	Electrical head-lighting and tail-lighting for motorcycles	Lights, interior, for motor vehicles	Ultraviolet lamps	Explosion-proof lamps	Arc-lamps	Metal halide lamps	Sodium vapor lamps	Electric mercury vapor lamps	Fluorescent lamps, hot cathode	Numerical indicator tubes, fluorescent type	Other discharge lamps
Belgium	2.821	0.075	0.031	0.167	–	0.004	77.793	20.966	0.296	0.888	–	18.459
Britain	11.182	1.193	3.654	26.617	19.823	0.292	7.175	3.044	3.015	18.755	0.021	4.541
China	285.161	53.341	15.375	33.244	87.477	0.104	79.457	63.507	324.583	8597.593	3.538	284.839
Canada	0.265	–	0.017	0.772	–	0.005	–	–	0.005	76.017	–	0.065
Czech	52.933	0.053	0.009	–	0.960	–	–	–	–	–	–	–
France	28.139	0.017	0.79	0.098	–	0.041	0.478	–	–	23.766	–	0.506
Germany	298.418	0.264	19.207	8.906	50.181	22.393	45.283	7.050	17.572	324.974	0.011	192.697
Holland	1.713	–	–	0.053	–	–	0.452	–	0.028	453.797	–	24.347
Hungary	0.085	–	–	1.305	–	–	7.803	9.311	–	74.353	–	0.025
Hong Kong	14.282	0.445	1.582	0.324	0.001	0.017	4.119	0.191	7.815	3.833	–	24.045
Indonesia	2.704	–	2.396	0.040	–	–	0.288	–	–	156.919	–	0.004
Italy	4.067	0.302	0.019	0.795	40.014	–	0.086	0.018	0.031	71.138	–	15.826
Japan	1008.75	7.445	126.529	171.351	63.911	2.326	19.752	7.280	2436.65	1251.354	61.819	183.784
Korea	383.742	7.654	78.654	0.555	28.062	0.006	1.311	0.100	8.683	103.880	1.615	4.427
Philippines	0.051	–	–	0.077	–	–	–	–	0.069	459.584	12.338	0.006
Poland	2.877	–	0.044	–	–	–	0.039	–	–	82.088	–	0.004
Sweden	52.303	0.085	0.469	0.008	–	–	–	–	0.003	–	–	0.081
Thailand	837.426	0.394	0.734	0.003	–	–	–	–	–	1013.052	–	1.284
United States	122.447	0.147	14.926	131.780	258.159	1.645	41.134	21.753	2.384	185.519	0.017	25.976
Others	3.11	0.060	0.108	0.029	–	0.145	7.682	0.826	4.084	276.204	0.354	1.528

Data source: Arranged from TAITRA and Bureau of Foreign Trade of Taiwan.

Table 4
The declaration of mercury/fluorescent powder-containing light sources and waste fluorescent tubes in 2002–2004 (t)

	Declaration of mercury- or fluorescent powder-containing light sources[a]	Waste fluorescent tubes
2002	1.6	524.0
2003	21.9	7891.7
2004	73.4	4363.7

Data source: Arranged from Taiwan EPA.
[a] High intensity discharge (HID) and straight daylight lamps are not included.

However, according to the data from Taiwan EPA and the industrial waste treatment companies, it was reported that 73.4 t of waste SHPs with 80 kg mercury were treated. This implies that 5660 mg mercury in average was contained in each SHP. Thus, 146 kg mercury in SHP was imported and wasted in year 2004. This 146 kg mercury had been also treated well in the industrial waste treatment processes.

Finally, according to the data from Directorate General of Customs in Taiwan, 551,500 and 65,000 UV lamps were imported and exported in year 2004. This reveals that 14 and 2 kg mercury were imported and exported in Taiwan, due to the average mercury-contained was 25 mg per UV lamp. Thus, 12 kg mercury had been treated in the industrial waste treatment processes.

According to the above estimation, it reveals that 165 kg mercury, i.e., 7 kg mercury contained in defective CCFLs, 146 kg mercury contained in waste SHPs, and 12 kg mercury contained in UV lamps, should be treated in the industrial waste treatment processes. However, only 133 kg mercury in total (80 kg plus 53 kg), was treated domestically and abroad. The waste mercury from high technology industries treated domestically has been undergone both thermal desorption and multiple distillation methods to recover and purify the mercury, which could obtain mercury up to a purity of 99.999%. On the other hand, the waste mercury treated abroad was sent to the Advanced Environmental Recycling Corporation in the Pennsylvania State of the United States.

Table 5
The fate of mercury-containing light sources in Taiwan in year 2004

Light source	Flow	Lamps quantity (lamps)	Average mercury content (mg/lamp)	Amount of mercury (kg)
CCFLs	Production (defective lamps)	132,033,300 (4,833,300)	1.5 (0.5–2.5)	*198* (*7*)
	Import	351,950,100	1.5 (0.5–2.5)	528
	Export	37,658,500	1.5 (0.5–2.5)	57
	Usage for other industrial products	441,491,400	1.5 (0.5–2.5)	662
	Domestic sales	132,447,400	1.5 (0.5–2.5)	199
	Abroad sales	309,044,000	1.5 (0.5–2.5)	463
	Waste	4,833,500	1.5 (0.5–2.5)	7
SHP	Production (defective lamps)	–	–	–
	Import	25,700	5600	146
	Export	–	–	–
	Usage for other industrial products	–	–	–
	Domestic sales	–	–	–
	Abroad sales	–	–	–
	Waste	25,700	5600	146
UV lamps	Production (defective lamps)	–	–	–
	Import	551,500	25 (4–60)	14
	Export	65,000	25 (4–60)	2
	Usage for other industrial products	–	–	–
	Domestic sales	–	–	–
	Abroad sales	–	–	–
	Waste	486,500	25 (4–60)	12

Table 6
The sale quantity of the four predominant panel manufactories in Taiwan

	Production (pieces)	Quantity of sale (pieces)	Quantity of sale (pieces)		Distribution (%)	
			Domestic sale	Abroad sale	Domestic sale	Abroad sale
AU Optronics Corp.	58,019,000	52,095,000	17,760,000	34,335,000	34	66
ChiMei Optoelectronics	13,609,028	12,438,833	4,682,094	7,756,739	38	62
ChungHwa Picture Tubes	11,017,000	10,876,000	567,000	10,309,000	5	95
HannStar Display Corp.	5,739,467	5,503,559	358,566	5,144,993	7	93
Total	88,384,495	80,913,392	23,367,660	57,545,732	30	70

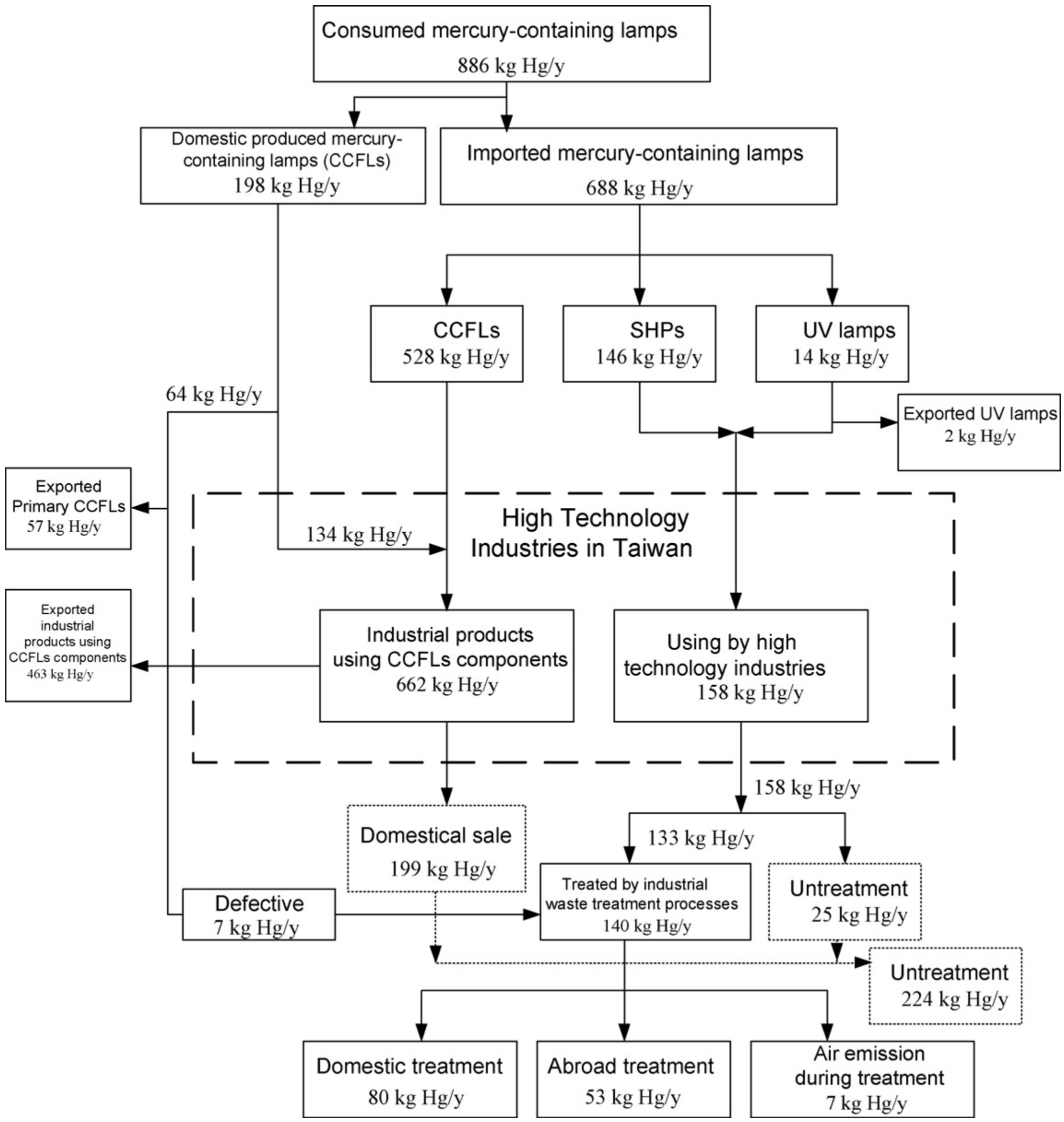

Fig. 1. The fates of mercury in mercury-containing lamps in high technology industries in Taiwan, 2004.

It was also reported that some of the lamps were broken during treatment, especially during the collection and sorting of the tubes. When the lamps are crushed, about 5% of contained-mercury is emitted to the air [1,4]. This reveals that 7 kg (133/0.95 = 7) mercury was emitted to the air during treated domestically and abroad. This implies that although 165 kg mercury was wasted from the high technology industries, only 140 kg mercury was treated in the industrial waste treatment processes. Thus, up to 25 kg mercury did not recover by the industrial waste treatment processes and might be harmful to the environment in year 2004.

For the overall estimation, it was calculated that total input of mercury contained in CCFLs, UV lamps, and SHPs was 886 kg in year 2004, while 59, 7, and 820 kg mercury was exported as primary CCFLs (57 kg) and UV lamps (2 kg), waste as defective CCFLs, and using in the high technology industries, respectively. In addition, for the 820 kg industrial used mercury, 463 and 199 kg mercury contained in exported and domestic sale of industrial products using CCFLs as components. However, the latter one was waste without any formal industrial treatment procedure. On the contrary, since 158 kg mercury contained in SHPs and UV lamps was used domestically, it reveals that 364 kg mercury was consumed in Taiwan during year 2004. In addition, 140 kg mercury of the 364 kg mercury contained in lamps used by high technology industry was well treated into industrial waste treatment system. Among this mercury wasted from high technology industry, it was calculated that 80, 53, and 7 kg mercury was domestic treatment, offshore treatment and emission in air, respectively. They are corresponding to 57, 38, and 5% of the 140 kg waste mercury. Unfortunately, 224 kg waste mercury was not suitable treated, including 199 kg mercury contained in CCFL and 25 kg non-treated mercury. Therefore, it is

Table 7
The comparison of mercury-containing light source between Taiwan and Denmark

Light source	Country (year)	Quantity (lamps)	Average mercury content (mg/lamp)	Total mercury estimation method	Consumption of mercury in light sources (kg)
Fluorescent tubes	Taiwan (2004[a])	80,000,000	10	Quantity × concentration	800
	Denmark (2001)	4228,000	10	Quantity × concentration	42
UV lamps	Taiwan (2004)	486,500	25	Quantity × concentration	12
	Denmark (2001)	263,000	25	Quantity × concentration	7
CCFLs	Taiwan (2004)	137,114,000	1.5	Quantity × concentration × 30%	199
	Denmark (2001)	1,700,000	3	Quantity of sale in 2001 × quantity × concentration	5
HID lamps[b]	Taiwan (2003[c])	255,500	30	Quantity × concentration	7.6
	Denmark (2001)	326,000	31	Quantity × concentration	10

[a] Reference [4].
[b] HID lamps include high pressure mercury lamps, metal halide lamps, high pressure sodium vapor lamps.
[c] Reference [9].

an important issue for Taiwan government to recover the mercury from the waste mercury-containing products to achieve the zero wastage policy in Taiwan.

3.3. A comparison of the mercury fate between Taiwan and Denmark

Although the usage of mercury was decreasing significantly in recent years, there are still a lot of mercury compound used in many different purposes, especially in industrial products. Therefore, several studies have been done for the mercury flow analysis, in which the recent one has been done by the Denmark EPA. The EPA in Denmark carried out a project “Mass Flow Analyses of Mercury 2001” to investigate the storage and flow of 12 mercury-containing products, included the mercury-containing light sources, in Denmark society in year 2004. Thus, this study further compared the fate of mercury-containing lamps, especially the fluorescent tubes, CCFLs, UV lamps, and HID lamps, between Taiwan and Denmark, as showed in Table 7. For the UV and HID lamps, both results survey from Taiwan and Denmark are similar. However, the mercury contained in fluorescent tubes and CCFLs are significantly different. It was observed that the consumption of mercury-containing fluorescent tubes in Taiwan is 20 times higher than in Denmark, due to the different in population, estimation method and fluorescent tube types. In Taiwan, there are 23 million people living in a 36,000 km^2 small island, while in Denmark only 5.3 million people living 43,000 km^2 areas. On the other hand, most fluorescent tubes are traditional mercury-containing daylight lamps in Taiwan, while in Denmark more than 90% of fluorescent tubes are non-mercury-contained. Additionally, the mercury consumption in CCFLs in Taiwan is 40 times higher than that in Denmark, due to the fact that Taiwan is the second major panel production country in the world. Finally, according to the total mercury consumption, included the usage of mercury-containing products other than fluorescent tubes, UV lamps, HID lamps, and CCFLs, the overall mercury loading in Taiwan is 42 g/(year km^2), 29 times higher than it in Denmark of 1.45 g/(year km^2). Thus, the Taiwan government should notice this situation and lower the mercury loading to prevent the hazard in the future.

4. Conclusion

This study investigated the fate of mercury of CCFLs, UV lamps, and SHPs of high technology industry in Taiwan using MFA method. It was observed that 479,150,100 CCLFs, 551,500 UV lamps, and 25,700 SHPs were produced domestically or imported in year 2004, contained total of 879 kg mercury. On the contrary, 37,658,500 CCFLs and 65,000 UV lamps were exported, contained total 59 kg mercury. It was also estimated that 165 kg mercury was wasted. Among this wasted mercury, 140 kg mercury, i.e., 4,833,300 CCFLs, 486,500 UV lamps, and 25,700 SHPs, were treated through the industrial waste treatment process, while 25 kg mercury did not recover by the industrial waste treatment processes and might be harmful to the environment in year 2004. The 140 kg treated mercury was contributed by 80 kg of domestic treatment (57%), 53 kg of abroad treatment (38%), and 7 kg of air emission (5%). Additionally, the mercury contained in CCFLs used as components of other industrial products was 662 kg, which were 463 kg for export and 199 kg for domestic sale. There is no suitable policy used in Taiwan to recover such 199 kg mercury-containing industrial products. Thus, it should be mind that to enhance the recovery of mercury, fluorescent powder, and valuable metals.

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