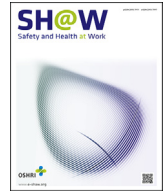




Contents lists available at ScienceDirect

Safety and Health at Work

journal homepage: www.e-shaw.org

Original Article

Developing Asbestos Job Exposure Matrix Using Occupation and Industry Specific Exposure Data (1984–2008) in Republic of Korea

Sangjun Choi^{1,2,*}, Dongmug Kang³, Donguk Park⁴, Hyunhee Lee³, Bongkyoo Choi²¹ Department of Occupational Health, Catholic University of Daegu, Geyongsangbukdo, Republic of Korea² Center for Occupational and Environmental Health, University of California, Irvine, CA, USA³ Department of Occupational and Environment Medicine, Pusan National University Yangsan Hospital, Yangsan, Republic of Korea⁴ Department of Environmental Health, Korea National Open University, Seoul, Republic of Korea

ARTICLE INFO

Article history:

Received 1 July 2016

Accepted 20 September 2016

Available online 29 September 2016

Keywords:

asbestos

asbestos-related diseases

JEM

mesothelioma

ABSTRACT

Background: The goal of this study is to develop a general population job-exposure matrix (GPJEM) on asbestos to estimate occupational asbestos exposure levels in the Republic of Korea.

Methods: Three Korean domestic quantitative exposure datasets collected from 1984 to 2008 were used to build the GPJEM. Exposure groups in collected data were reclassified based on the current Korean Standard Industrial Classification (9th edition) and the Korean Standard Classification of Occupations code (6th edition) that is in accordance to international standards. All of the exposure levels were expressed by weighted arithmetic mean (WAM) and minimum and maximum concentrations.

Results: Based on the established GPJEM, the 112 exposure groups could be reclassified into 86 industries and 74 occupations. In the 1980s, the highest exposure levels were estimated in “knitting and weaving machine operators” with a WAM concentration of 7.48 fibers/mL (f/mL); in the 1990s, “plastic products production machine operators” with 5.12 f/mL, and in the 2000s “detergents production machine operators” handling talc containing asbestos with 2.45 f/mL. Of the 112 exposure groups, 44 groups had higher WAM concentrations than the Korean occupational exposure limit of 0.1 f/mL.

Conclusion: The newly constructed GPJEM which is generated from actual domestic quantitative exposure data could be useful in evaluating historical exposure levels to asbestos and could contribute to improved prediction of asbestos-related diseases among Koreans.

© 2016, Occupational Safety and Health Research Institute. Published by Elsevier. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

1. Introduction

The International Agency for Research on Cancer concluded that all forms of asbestos, including chrysotile, are causally associated with an increased risk of cancer of the lungs, larynx, and ovary, and mesothelioma and asbestosis [1]. In 2006, the World Health Organization (WHO) campaigned for the elimination of asbestos-related diseases (ARDs) and recommended that the most efficient way to eliminate ARDs is to cease using all types of asbestos [2]. Recently, the WHO reported that there are about 125 million people in the world exposed to asbestos at the workplace, and at least 107,000 people die each year from asbestos-related lung cancer, mesothelioma, and asbestosis due to occupational exposures [3]. In its 2014 update, the WHO reiterated the call for global campaigns to eliminate ARDs. However, despite the international clamor to

eliminate ARD cases coupled with abundant scientific evidence on the carcinogenicity of asbestos, the production and use of asbestos at the global scale did not decrease but rather increased slightly to 2.02 million Mg in 2013 from 2.01 million Mg in 2012. Russia was the leading producer of asbestos, followed by China, Brazil, and Kazakhstan, comprising 99% of the world asbestos production. However, China ranks first in terms of industrial utilization of asbestos. In general, Southeast Asian countries continued to lead in the manufacture of asbestos products and accounted for about 69% of global asbestos use in 2012 [4]. Aside from China, the Republic of Korea was also one of the largest asbestos-utilizing countries in Asia. According to the data on mineral supply of the Korea Institute of Geoscience and Mineral Resources, the domestic asbestos production in the Republic of Korea was about 7 tons in 1933 and continuously increased to 15,933 tons in 1982 [5]. This was

* Corresponding author. Department of Occupational Health, Catholic University of Daegu, 13-13 Hayang-ro, Geyongsan, 38430, Republic of Korea.
E-mail address: junilane@gmail.com (S. Choi).

followed by a rapid decline of asbestos production after 1984 which resulted in the importation of asbestos for industrial use. In fact, the demand for asbestos for industrial utilization in the Republic of Korea is entirely dependent on imports from other countries. The amount of asbestos imported from other countries was about 38,028 tons in 1971 and increased to as high as 95,000 tons in 1992, but gradually declined until 2005. Since 2009, there is a total ban on the use of all kinds of asbestos as a government precautionary intervention of ARD outbreaks such as the “Kubota shock” that happened in Japan [6].

The total ban of using all types of asbestos as a national policy can be an effective intervention to reduce ARDs [7]. However, studies have shown that the occurrence of ARDs do not only result from direct and immediate exposure to asbestos but also are largely determined by the historical exposure to asbestos of the patients affected with ARDs [1,8]. It should be emphasized that under the Korean scenario, historical exposure to asbestos is an important factor for ARD occurrence because these materials have been used in building construction until the 2000s [9]. In order to effectively prevent and predict occupational cancers with a long latency such as ARDs, it is very important to create a general population based job-exposure matrix (GPJEM) using historical exposure databases that are in accordance to the current standardized industrial and occupational code. However, to the best of our knowledge, there is no Korean asbestos GPJEM built on standardized industrial and occupational codes. The purpose of this study is to construct a GPJEM for asbestos using quantitative occupational exposure data available in the Republic of Korea. The results of this study can be used to make a surveillance system supporting the prevention of ARDs.

2. Materials and methods

2.1. Quantitative occupational exposure data collection

Three Korean domestic quantitative datasets on the occupational exposure to airborne asbestos were used to build the GPJEM. The first data source was domestic peer-reviewed literatures on asbestos. For asbestos-related literatures, the search terms “asbestos,” “chrysotile,” “amosite,” “actinolite,” “tremolite,” “crocidolite,” “asbestosis,” “lung cancer,” and “mesothelioma” were used singly or in combination in the Research Information Sharing Service (<http://www.riss.kr>) operated by the Korea Education and Research Information Service. Among the literature searched, only occupational exposure data were used for GPJEM. The second dataset was workplace monitoring data analyzed from 1995 to 2006 at the Industrial Hygiene Laboratory of the Graduate School of Public Health, Seoul National University (GSPH-SNU), Seoul, Republic of Korea. The laboratory has been analyzing mostly airborne asbestos samples collected by the Work Environment Monitoring Agency under Article 42 of the Industrial Safety and Health Act, Republic of Korea. The last source was the work environment monitoring data of asbestos reported to the Korea Occupational Safety and Health Agency (KOSHA) from 2005 to 2008.

2.2. Classification of industries and occupations

Exposure groups in collected data were reclassified based on standardized industrial and occupational codes currently implemented in the Republic of Korea. For industrial codes, the 9th edition of the Korean Standard Industrial Classification (KSIC), finalized and notified as the Korea National Statistical Office Notification #2007-53 (December 28, 2007) and took effect on February 1, 2008, was used. The reclassification was conducted in order to reconcile the industrial characteristics of previous exposure groups

to the industrial classification currently employed in the Republic of Korea. For occupational codes, the 6th Korean Standard Classification of Occupations (KSCO), finalized and notified as the Korea National Statistical Office Notification #2007-3 (July 2, 2007), was used to reflect the International Standard Classification of Occupations (08) finalized and implemented at the end of 2007. The reclassification of different exposure groups facilitated conformity and comparability of the Korean GPJEM with international standards of classification. Two trained industrial hygienists cross checked the accuracy of classification results. We tried to classify all of the exposure groups according to the five-digit level of the KSIC and KSCO. If there were conflicts of results classified by two industrial hygienists, we determined the upper classes such as the four-digit or three-digit level.

2.3. Data analysis

Arithmetic mean (AM) was used as a representative value for the analysis of the measurements which is considered as the best summary measure of exposure for epidemiologic studies of chronic diseases [10]. Since not all the data obtained for the study have AM, data transformation was conducted. If the asbestos concentrations were reported using the geometric mean and geometric standard deviation in literature, a lognormal distribution was assumed and an AM was estimated using the following formula (1) [11]:

$$AM = \text{geometric mean} \times \exp\left[\frac{1}{2} \times (\ln(\text{geometric standard deviation}))^2\right] \quad (1)$$

In cases where asbestos concentration was reported with a range of minimum–maximum, the AM was estimated by assuming a lognormal distribution according to the following method: first, the midpoint of the log transformed minimum and maximum levels provided an estimate of the mean of the log transformed levels ($\hat{\mu}_L$); second, the range of the log transformed levels divided by four provided an estimate of the standard deviation of the log transformed levels ($\hat{\sigma}_L$); and finally, AM was calculated using the following formula (2):

$$AM = \exp\left[\hat{\mu}_L + \frac{1}{2} \times \hat{\sigma}_L^2\right] \quad (2)$$

When the data collected is based on different numbers (N) of observations, the weighted average was calculated by computing the weight of each group that is proportional to the inverse of the variance of the mean [12]. Because we did not have variance estimates, weighted arithmetic means (WAMs) were calculated using the following formula (3).

$$WAM = (N_1 \times AM_1 + N_2 \times AM_2 + \dots + N_n \times AM_n) / N_t \quad (3)$$

Finally, all of the exposure data were reclassified as a similar exposure group according to measurement years, industries, and occupations. As there was no information on measurement years, we regarded publication years of cited literature as measurement years.

3. Results

The exposure data of asbestos used in this study were summarized in Table 1. A total of 112 exposure groups could be classified using 5,627 quantitative exposure data from 1984 to 2008. Each exposure group has similar exposure characteristics including exposure duration, industry, and occupation. The WAM concentrations of the 112 exposure groups ranged from 0.0002 fibers/mL

Table 1
Summary of data collected by resources

Resources	No. of exposure groups	No. of samples	No. of industries	No. of occupations	Measurement years	Range of WAM (f/mL)	Maximum (f/mL)
Literature	11	641	8	8	1984–1996	0.02–7.5	17.3
SNU DB	43	2,124	42	38	1995–2006	0.005–5.1	26.7
KOSHA DB	58	2,862	50	46	2005–2008	0.0002–2.4	8.4
Total	112	5,627	86	74	1984–2008	0.0002–7.5	26.7

f/mL, fibers per mL; KOSHA DB, Korea Occupational Safety and Health Agency database; SNU DB, Seoul National University database; WAM, weighted arithmetic mean.

(f/mL) to 7.5 f/mL. The detailed results of GPJEM according to three data sources from literature, and the GSPH-SNU and KOSHA databases were listed in a descending order of WAM concentrations in Tables 2–4, respectively.

Specifically, the GPJEM based on literature from 1984 to 1996 consisted of 11 exposure groups belonging to nine types of industries and nine types of occupations (Table 2). Most of the industries involved in this dataset belonged to exposure groups from primary asbestos industries. These are industries that dealt with manufacturing asbestos-containing products such as asbestos textile, slate, and auto-vehicle brake lining, which involve directly handling raw asbestos. Most of the exposure groups (EG01–EG10) had higher WAM concentrations than the Korean occupational exposure limit (OEL) of 0.1 f/mL. The workers involved in knitting and weaving machine operations (KSCO code: 8221) in the industry manufacturing asbestos, mineral wools, and other similar products (KSIC code: 23994) showed the highest WAM concentration of 7.48 f/mL from 1984 to 1989, which was two times higher than the WAM level of 2.55 f/mL, from the same category during the period of 1991 to 1996 (Table 2). All other exposure groups had WAM values between 0.02 f/mL and 1.54 f/mL asbestos levels.

Table 3 shows the 43 exposure groups (EG12–EG54) constructed based on the GSPH-SNU database from 1995 to 2006. Among these 43 exposure groups, seven groups (EG12–EG18) had higher WAM concentrations than the Korean OEL (0.1 f/mL) and an additional 22 groups (EG19–EG40) had higher WAM concentrations than the Korean indoor air quality guideline (0.01 f/mL). The highest exposure to asbestos on this database occurred among workers under the plastic products production machine operators (KSCO code: 83239) working at industry “manufacturing foamed plastic products” (KSIC code: 22250) with a WAM concentration of 5.12 f/mL from 1996 to 1997. The maximum concentration was reported as 26.7 f/mL from workers under the automobile parts assemblers (KSCO code: 85429) working at the industry “manufacturing parts and accessories for motor vehicles and engines” (KSIC code: 303). The type of samples belonging to this category was not indicated.

Table 4 lists the characteristics of 58 exposure groups (EG55–EG112) based on the KOSHA database. The exposure levels of 27 groups (EG55–EG81) were over the Korean OEL and the next 12 groups (EG82–EG93) showed a higher level than the Korean indoor air quality guideline. The highest exposure level was 8.42 f/mL recorded from personal exposure of workers working as operators of detergent production machines (KSCO code: 83213) handling talc containing anthophyllite. These workers belonged to the industry “manufacturing surface-active agents” (KSIC code: 20431).

4. Discussion

In this study, we focused on the construction of a GPJEM using the standardized code of the industry and occupations because the characteristics and trends of occupational asbestos exposure in the Republic of Korea were previously reported by Park et al [5] in 2008.

Many GPJEMs on asbestos have been developed for epidemiological studies, like the Finnish JEM [20], the Dutch JEM [21],

and Australian JEM [22]. In constructing GPJEM at a national level, it is essential to use reliable quantitative exposure data measured within the country. We constructed 112 exposure groups with 86 industries and 74 occupations from three kinds of domestic exposure databases. The reclassification and data transformation of the different exposure group databases enable us to make direct comparison of the different exposure values which could not be possible using the raw data. However, the GPJEM constructed in this study should be used with careful consideration based on the characteristics of each database used as follows.

The GPJEM for the first period suggests that exposure evaluations mostly covered the asbestos exposure from slate manufacturing, asbestos textile and brake lining manufacturing, and motor vehicle maintenance industries that directly handled asbestos to manufacture a product. Also included are the asbestos exposures of workers from the ship demolition industry which has the potential of high-concentration exposure to asbestos. Looking at the history of asbestos production and consumption in the Republic of Korea and the bulk of published literature available, it could be noted that there is very limited literatures containing information about the primary asbestos industry during the period prior to 1996. Considering that the Republic of Korea has a long history of slate manufacturing with asbestos (the asbestos textile industry has more than 20 years of history since 1969, and the brake lining manufacturing industry started from the mid-1970s), it appeared that there is a shortage of published literature compared with the extensiveness of the asbestos industry during this period. This could be attributed to the fact that the exposure status for asbestos in workplaces in the Republic of Korea was first surveyed in 1984 in asbestos slate manufacturing workplaces, brake lining workplaces, and asbestos textile industries by the National Institute of Labor Science (NILS) under the Ministry of Labor [13]. It should also be noted that the methods used for monitoring and analysis during this early period were different from the current methodology used by the National Institute for Occupational Safety and Health 7400 standard methods [23]. In contrast, the methodology employed by GSPH-SNU and the NILS for the joint survey of asbestos slate manufacturing workplaces and asbestos textile industry from 1987 conformed with the present standard methods. After the joint investigation conducted by GSPH-SNU and NILS, social interests in asbestos have increased and the risks of asbestos became widely acknowledged, prompting work environment monitoring and management of asbestos-using workplaces to take place.

In the case of the GSPH-SNU database, reliability of data could be ensured as they were analyzed at an officially designated analytical institution by the Ministry of Labor. The laboratory is also quality controlled under the National Institute for Occupational Safety and Health Proficiency Analytical Testing program—a globally-recognized accreditation program. The fact that data were analyzed in a single institution also makes it unlikely to have between-institution errors. Finally, most of the asbestos samples collected by industrial hygiene laboratories in the Republic of Korea were sent for analysis to GSPH-SNU from 1995 to 2006, so that the

Table 2
Job-exposure matrix based on literature from 1984 to 1996

Exposure group	Reference	Measurement years	Industry (KSC Rev. 9)		Occupation (KSCO Rev. 6)		Sample	n	WAM (f/mL)	Min. (f/mL)	Max. (f/mL)	Job or sampling description
			Code	Name	Code	Name						
EG01	[13], [14], [15]	1984–1989	23994	Manufacture of asbestos, mineral wools, and other similar products	8221	Knitting and weaving machine operators	P/A	178	7.48	0.07	14.90	Manufacturing of asbestos textile
EG02	[16], [17], [18], [19]	1991–1996	23994	Manufacture of asbestos, mineral wools, and other similar products	8221	Knitting and weaving machine operators	P/A/NI	121	2.55	0.03	17.30	Manufacturing of asbestos textile
EG03	[15]	1988–1989	2431	Cast of iron and steel	84110	Metal casting machine operators	P	13	1.54	0.01	11.40	Welding with asbestos cloth
EG04	[15]	1988	4521	Sale of motor vehicle new parts and accessories	52119	Store salespersons n.e.c.	P	NI	1.41	0.16	5.64	Handling of auto-vehicle brake for selling
EG05	[16]	1991	95212	Repair services of motor vehicles specializing in parts	7510	Automobile mechanics	P	51	1.05	0.01	7.28	Repair of auto-vehicle brake lining
EG06	[15]	1988–1989	95212	Repair services of motor vehicles specializing in parts	7510	Automobile mechanics	P	12	0.93	0.01	7.28	Repair of auto-vehicle brake lining
EG07	[16], [18], [19]	1991–1996	23911	Manufacture of stone products for construction	84341	Mineral ore and stone products processing machine operators	P/NI	70	0.74	0.02	4.75	Manufacturing of asbestos slate
EG08	[13], [14], [15]	1984–1989	23911	Manufacture of stone products for construction	84341	Mineral ore and stone products processing machine operators	P/A/NI	36	0.46	0.1	1.23	Manufacturing of asbestos slate
EG09	[13], [16], [18], [19]	1984–1994	30399	Manufacture of other parts and accessories for motor vehicles n.e.c.	85429	Automobile parts assemblers n.e.c.	P/NI	147	0.42	0	3.08	Manufacturing of asbestos brake lining
EG10	[15]	1988	95119	Other maintenance and repair services of general machinery	75220	Ship mechanics	P/A	13	0.23	0.01	2.45	Repair of ship
EG11	[19]	1994	31111	Building of steel ships	85432	Ship assemblers	NI	NI	0.02	NI	NI	Ship building

A, area; EG, exposure group; f/mL, fibers per mL; KSCO, Korean Standard Classification of Occupations; KSIC, Korean Standard Industrial Classification; Max., maximum; Min., minimum; n.e.c., not elsewhere classified; NI, no information; P, personal; Rev., revision; WAM, weighted arithmetic mean.

Table 3
Job-exposure matrix based on the Seoul National University database from 1995 to 2006

Exposure group	Measurement years	Industry (KSC Rev. 9)		Occupation (KSCO Rev. 6)		Sample	n	WAM (f/mL)	Min. (f/mL)	Max. (f/mL)
		Code	Name	Code	Name					
EG12	1996–1997	22250	Manufacture of foamed plastic products	83239	Plastic products production machine operators n.e.c.	NI	12	5.12	0.02	13.94
EG13	1995–1996	17909	Manufacture of other articles of paper and paperboard n.e.c.	89190	Wood and paper related machine operators n.e.c.	NI	16	3.54	0.05	11.97
EG14	1995–2006	13213	Weaving of man-made fiber fabrics	82211	Weaving machine operators	NI	64	1.52	0.005	7.41
EG15	1996–2005	23992	Manufacture of abrasive articles	84392	Brightener production machine operators	NI	80	0.56	0.002	2.77
EG16	1995–2006	303	Manufacture of parts and accessories for motor vehicles and engines	85429	Automobile parts assemblers n.e.c.	NI	1,089	0.18	0.0005	26.68
EG17	1995–2002	23994	Manufacture of asbestos, mineral wools, and other similar products	8221	Knitting and weaving machine operators	NI	40	0.14	0.005	2.37
EG18	1995–2006	31111	Building of steel ships	75220	Ship mechanics	NI	113	0.13	0.0005	1.68
EG19	1995	31322	Manufacture of aircraft parts and accessories	85433	Aircraft assemblers	NI	11	0.09	0.005	0.32
EG20	1995–2003	95212	Repair services of motor vehicles specializing in parts	7510	Automobile mechanics	NI	57	0.08	0.005	3.29
EG21	1995–2003	30310	Manufacture of parts and accessories for motor engines	85421	Automobile engine assemblers	NI	44	0.07	0.005	0.79
EG22	1995–1997	13993	Manufacture of special yarns and tire cord fabrics	8211	Textile processing machine operators	NI	14	0.0732	0.005	0.47
EG23	1995–2006	23999	Manufacture of other unclassified nonmetallic minerals n.e.c.	84399	Nonmetal products related production machine operators n.e.c.	NI	128	0.069	0.005	0.800
EG24	1997–1999	23229	Manufacture of other refractory ceramic products	84322	Brick and tile molding machine operators	NI	6	0.0642	0.005	0.11
EG25	1996–1999	31114	Manufacture of sections for ships	85432	Ship assemblers	NI	11	0.0573	0.005	0.17
EG26	1995	29210	Manufacture of agricultural and forestry machinery	85442	Agricultural machinery assemblers	NI	4	0.0463	0.005	0.1
EG27	1995–2003	20302	Manufacture of synthetic resin and other plastic materials	83239	Plastic products production machine operators n.e.c.	NI	20	0.0431	0.005	0.72
EG28	1995–2006	24121	Manufacture of hot rolled, drawn, and extruded iron or steel products	84151	Rolling mill operators	NI	33	0.04	0.0005	0.35
EG29	1996–2006	41112	Apartment building construction	772	Construction related technical worker	NI	24	0.0393	0.004	0.32
EG30	2001	52911	Supporting, railway transport activities	75232	Railroad train mechanics	NI	17	0.0371	0.005	0.16
EG31	1995	23994	Manufacture of asbestos, mineral wools and other similar products	84322	Brick and tile molding machine operators	NI	1	0.03	0.03	0.03
EG32	1996	2642	Manufacture of broadcasting and wireless telecommunication apparatuses	86409	Electrical, electronic parts, and products assembler n.e.c.	NI	8	0.0281	0.005	0.19
EG33	1995–2005	30121	Manufacture of passenger motor vehicles	85410	Automobile assemblers	NI	77	0.0233	0.004	1.03
EG34	1997–1998	26529	Manufacture of other sound equipment	86402	Audio-visual equipment assemblers	NI	8	0.0219	0.005	0.04

(continued on next page)

Table 3 (continued)

Exposure group	Measurement years	Industry (KSIC Rev. 9)		Occupation (KSCO Rev. 6)		Sample	n	WAM (f/mL)	Min. (f/mL)	Max. (f/mL)
		Code	Name	Code	Name					
EG35	2005	21300	Manufacture of pharmaceutical goods other than medicaments generators	83211	Pharmaceutical products production machine operators	NI	5	0.0162	0.003	0.049
EG36	1999	28111	Manufacture of electric motors and generators	86401	Electrical equipment assemblers	NI	7	0.0143	0.005	0.04
EG37	1998–2005	22299	Manufacture of other plastic products n.e.c.	83239	Plastic products production machine operators n.e.c.	NI	19	0.0119	0.001	0.07
EG38	1995–2006	22199	Manufacture of other rubber products n.e.c.	83222	Rubber products production machine operators	NI	64	0.0117	0.0005	0.06
EG39	1999–2006	26299	Manufacture of other electronic valves, tubes and electronic components n.e.c.	86321	Electronic parts production equipment operators	NI	21	0.0106	0.001	0.05
EG40	1996–2006	20111	Manufacture of basic organic petrochemicals	83219	Chemical products production machine operators n.e.c.	NI	9	0.0103	0.001	0.02
EG41	1998–2002	29169	Manufacture of other work trucks, lifting, and handling equipment	8544	General machinery assemblers	NI	10	0.009	0.005	0.03
EG42	1997–2001	25934	Manufacture of saws, saw blades, and interchangeable tools	74110	Die and mold makers	NI	7	0.0086	0.005	0.02
EG43	1995–2002	24119	Manufacture of other basic iron and steel	84141	Ore and metal furnace operators	NI	30	0.0082	0.005	0.04
EG44	1995–1996	29250	Manufacture of machinery for food, beverage and tobacco processing	811	Food processing related machine operating occupations	NI	9	0.0078	0.005	0.02
EG45	2002	25912	Forging of metal	74130	Forge hammer smiths and forging press workers	NI	2	0.0075	0.005	0.01
EG46	1995	22232	Manufacture of packaging plastics and shipping containers	83231	Plastic catapulating machine operators	NI	2	0.0075	0.005	0.01
EG47	2001–2002	20499	Manufacture of all other chemical products n.e.c.	83219	Chemical products production machine operators n.e.c.	NI	5	0.007	0.005	0.01
EG48	1997–2000	25913	Manufacture of metal pressed and stamped products	84151	Rolling mill operators	NI	9	0.0067	0.005	0.01
EG49	2002	23211	Manufacture of pottery and ceramic household or ornamental ware	84321	Pottery and porcelain products production machine operators	NI	14	0.0064	0.005	0.01
EG50	2002–2006	86101	General hospitals	24	Health, social welfare, and religion related occupations	NI	5	0.0056	0.003	0.008
EG51	1997–2001	6022	Broadcasting via cable, satellite, and other broadcasting	2240	Telecommunication and broadcast transmission equipment technicians	NI	12	0.0054	0.005	0.01
EG52	2000	29132	Manufacture of pumps and compressors	89904	Air compressor operators	NI	1	0.005	0.005	0.005
EG53	1996	28519	Manufacture of other domestic electric appliances	86312	Electrical products production equipment operators	NI	12	0.005	0.005	0.005
EG54	1996–2005	17129	Manufacture of other paper and paperboard	89132	Paper processing machine operators	NI	4	0.0047	0.0038	0.005

A, area; EG, exposure group; f/mL, fibers per mL; KSCO, Korean Standard Classification of Occupations; KSIC, Korean Standard Industrial Classification; Max., maximum; Min., minimum; n.e.c., not elsewhere classified; NI, no information; P, personal; Rev., revision; WAM, weighted arithmetic mean.

Table 4 Job-exposure matrix based on the Korean Occupational Safety and Health Agency database from 2005 to 2008

Exposure group	Industry (K SIC Rev. 9)		Occupation (K SCO Rev. 6)		Sample	n	WAM (f/mL)	Min. (f/mL)	Max. (f/mL)	Job or sampling description
	Code	Name	Code	Name						
EG55	20431	Manufacture of surface-active agents	83213	Detergents production machine operators	P	4	2.45	0	8.42	Handling talc containing anthophyllite
EG56	17129	Manufacture of other paper and paperboard	8914	Paper products production machine operators	P	2	1.61	0.308	2.91	Handling talc containing asbestos
EG57	17222	Manufacture of paperboard boxes and containers	84219	Painting machine operators n.e.c.	P	2	1.51	1.3699	1.64	Handling talc containing asbestos
EG58	2391	Cutting, shaping, and finishing of stone	77230	Construction stonemason	P	2	1.18	1.1281	1.24	Handling talc containing asbestos
EG59	20302	Manufacture of synthetic resin and other plastic materials	83121	Chemical material grinding and mixing machine operators	P	20	1.06	0.0483	1.96	Handling talc containing asbestos
EG60	30399	Manufacture of other parts and accessories for motor vehicles n.e.c.	75105	Automobile paint mechanics	P	9	1.05	0.1171	1.64	Handling talc containing asbestos
EG61	22191	Manufacture of industrial vulcanized rubber products	83229	Tire and rubber products production machine operators n.e.c.	P	9	0.96	0.13	1.80	Handling talc containing asbestos
EG62	95211	General repair services of motor vehicles	75105	Automobile paint mechanics	P	42	0.88	0	2.00	Handling talc containing asbestos
EG63	13102	Spinning of wool	8211	Textile processing machine Operators	P	2	0.74	0.0487	1.43	Handling talc containing asbestos
EG64	20302	Manufacture of synthetic resin and other plastic materials	84219	Painting machine operators n.e.c.	P	2	0.73	0.455	1.01	Handling talc containing asbestos
EG65	20302	Manufacture of synthetic resin and other plastic materials	83124	Chemical material distiller and reactor operators	P	5	0.6894	0	2.62	Handling additive containing anthophyllite
EG66	22111	Manufacture of tires and tubes	83221	Tire production machine Operators	P	96	0.658	0.065	2.437	Handling talc containing asbestos
EG67	20421	Manufacture of general paints and similar products	83121	Chemical material grinding and mixing machine operators	P	14	0.6188	0	1.1129	Handling talc containing asbestos
EG68	29133	Manufacture of taps, valves, and similar products	8510	Machine tool operators	P	3	0.556	0	1.2181	Handling talc containing asbestos
EG69	20301	Manufacture of synthetic rubber	83222	Rubber products production machine operators	P	13	0.4684	0	2.646	Handling talc containing anthophyllite
EG70	17222	Manufacture of paperboard boxes and containers	89141	Paper box and envelope products processing machine operators	P	9	0.4518	0.0487	1.43	Handling talc containing asbestos
EG71	31114	Manufacture of sections for ships	85432	Ship assemblers	P	5	0.4518	0	1.6438	Handling talc containing asbestos
EG72	28302	Manufacture of other insulated wire and cable	86402	Audio-visual equipment assemblers	P	6	0.3579	0.3004	0.4154	Handling talc containing asbestos
EG73	25119	Manufacture of other structural metal products	84213	Metal product painting machine operators	P	2	0.2113	0	0.4225	Handling talc containing asbestos
EG74	28410	Manufacture of electric lamps and electric bulbs	86312	Electrical products production equipment operators	P	7	0.2031	0	0.7131	Manufacturing of lamp for car

(continued on next page)

Table 4 (continued)

Exposure group	Industry (K SIC Rev. 9)		Occupation (KSCO Rev. 6)		Sample	n	WAM (f/mL)	Min. (f/mL)	Max. (f/mL)	Job or sampling description
	Code	Name	Code	Name						
EG75	28303	Manufacture of insulated codes sets and other conductors for electricity	86401	Electrical equipment assemblers	P	2	0.1245	0.0192	0.2297	Extrusion of electric cable
EG76	70129	Research and experimental development on other engineering	13114	Engineering research managers	P/A	8	0.1191	0	0.94	Sampling in laboratory
EG77	17902	Manufacture of sanitary paper products	89144	Sanitary paper products processing machine operators	P	16	0.1156	0	0.6314	Handling material containing amosite
EG78	29299	Manufacture of other special purpose machinery n.e.c.	85441	Industry machinery assemblers	P	4	0.1133	0	0.3146	Handling talc containing amosite
EG79	2030	Manufacture of synthetic rubber and of plastics in primary forms	8312	Chemical material processing machine operators	P	38	0.1128	0	1.148	Manufacturing of synthetic resin
EG80	17221	Manufacture of paper sacks and paper bags	84219	Painting machine operators n.e.c.	P	1	0.1125	0.1125	0.1125	Handling talc containing asbestos
EG81	221	Manufacture of rubber products	83239	Plastic products production machine operators n.e.c.	P	4	0.1097	0	0.2199	Mixing of epoxy resin
EG82	20493	Manufacture of adhesives and gelatin	83121	Chemical material grinding and mixing machine operators	P	3	0.0545	0	0.1153	Handling talc containing asbestos
EG83	31114	Manufacture of sections for ships	85432	Ship assemblers	P	16	0.0349	0	0.384	Ship machine processing
EG84	25921	Heat treatment of metals	84155	Metal heat treatment furnace operators	P	10	0.0337	0.001	0.239	Operation of furnace for heat treatment
EG85	30399	Manufacture of other parts and accessories for motor vehicles n.e.c.	85429	Automobile Parts Assemblers n.e.c.	P/A	139	0.0333	0	0.0956	Manufacturing of brake lining
EG86	15219	Manufacture of other footwear	721	Textile and leather related workers	A	3	0.0258	0.0118	0.0383	Area sampling in factory building constructed with asbestos-containing materials
EG87	20421	Manufacture of general paints and similar products	83121	Chemical material grinding and mixing machine operators	P	4	0.0209	0	0.0837	Manufacturing of paint
EG88	28422	Manufacture of general electric lighting fixture	86401	Electrical equipment assemblers	P	13	0.0197	0	0.1571	Manufacturing of general lamp
EG89	23994	Manufacture of asbestos, mineral wools, and other similar products	8433	Cement and mineral products production machine operators	P/NI	143	0.018	0.001	0.09	Manufacturing of asbestos gasket
EG90	382	Waste treatment services	8820	Recycling machine and incinerator operators	P	36	0.016	0	0.0578	Waste treatment
EG91	23324	Manufacture of cellulose fiber cement products	84331	Cement and lime production related machine operators	P	18	0.0134	0	0.071	Extruding molding of cement
EG92	38220	Disposal of hazardous waste	88209	Recycling machine and incinerator operator n.e.c.	P	6	0.013	0.0004	0.028	Crushing waste containing asbestos
EG93	20209	Manufacture of other fertilizers and nitrogen compounds	7724	Construction carpenters	P	1	0.0116	0.0116	0.0116	Sampling in the carpenter's shop

EG94	23199	Manufacture of all other glass and its products n.e.c.	84319	Glass production and processing machine operators n.e.c.	P	2	0.0065	0.0037	0.0093	Working around mercury filling and air vent machine
EG95	25924	Engraving, cutting, and similar processing of metals or other materials	84159	Metal processing machine operators n.e.c.	P	16	0.0061	0.001	0.024	Manufacturing of cutting tool
EG96	17110	Manufacture of pulp	89131	Paper pulp plant operators	A	2	0.006	0.004	0.008	Handling talc containing asbestos
EG97	38120	Hazardous waste collection	91001	Elementary workers in construction	P/A	1,926	0.005	0	1.9884	Sampling after dismantling asbestos
EG98	28119	Manufacture of other electric motors, generators, and transformers	86311	Electrical parts production equipment operators	P	3	0.004	0	0.0119	Manufacturing of rotary machine parts
EG99	3511	Electric power generation	8610	Power generation and distribution equipment operators	P/A	15	0.0036	0	0.0236	Maintenance work in power plant
EG100	52911	Supporting, railway transport activities	31262	Railway transport clerks	P	14	0.0034	0.001	0.011	Sampling in the station office
EG101	25911	Manufacture of powder metallurgic products	84159	Metal processing machine operators n.e.c.	P	12	0.0028	0	0.0101	Melting of metal powder
EG102	29210	Manufacture of agricultural and forestry machinery	83239	Plastic products production machine operators n.e.c.	P	8	0.0026	0.001	0.007	Manufacturing of agricultural machinery
EG103	30310	Manufacture of parts and accessories for motor engines	85421	Automobile engine assemblers	P	4	0.0023	0.001	0.003	Cutting with press machine
EG104	27216	Manufacture of industrial process control equipment	85101	Lathe machine operators	P	2	0.002	0.001	0.003	Operation of milling machine for electromagnetic clutch
EG105	68211	Residential property management	85201	Cooling and heating system operators	P	4	0.002	0	0.004	Management of boiler room in apartment
EG106	52911	Supporting, railway transport activities	7523	Railroad train and electric train mechanics	P	44	0.0018	0	0.01	Maintenance of locomotive and electric train
EG107	86101	General hospitals	24	Health, social welfare, and religion related occupations	P/A	10	0.0017	0	0.0046	Sampling in central supply room and repair shop
EG108	26299	Manufacture of other electronic valves, tubes, and electronic components n.e.c.	86321	Electronic parts production equipment operators	P	4	0.0015	0	0.003	Manufacturing of temperature sensor
EG109	95211	General repair services of motor vehicles	7510	Automobile mechanics	P	47	0.0013	0	0.01	Maintenance of auto-vehicles
EG110	303	Manufacture of parts and accessories for motor vehicles and engines	74130	Forge hammersmiths and forging press workers	P	16	0.0011	0	0.002	Manufacturing of auto parts
EG111	33999	Other manufacturing n.e.c.	83124	Chemical material distiller and reactor operators	P	2	0.001	0.001	0.001	Melting and molding
EG112	86103	Dental hospitals	24	Health, social welfare, and religion related occupations	P	12	0.0002	0	0.0021	Sampling in dental hospital

A, area; EG, exposure group; f/mL, fibers per mL; KSCO, Korean Standard Classification of Occupations; KSIC, Korean Standard Industrial Classification; Max., maximum; Min., minimum; n.e.c., not elsewhere classified; NI, no information; P, personal; Rev., revision; WAM, weighted arithmetic mean.

GSPH-SNU database provides the broadest spectrum data currently available. However, it has the weakness of having limited workplace parameter information. Since many institutions requesting for analysis had provided only basic information such as sampling time and flowrate, exposure groups in the GSPH-SNU database do not carry information on sample types. Therefore, 2,124 out of 3,642 originally collected data points were used in this study, as they could be linked to established industry and occupation codes. However, it was not possible to describe characteristics of jobs or sampling circumstances for 43 exposure groups from this database (Table 3).

From the work environment monitoring data reported to KOSHA, 2,862 monitoring data points were analyzed to build the GPJEM which is presented in Table 4. Since 2002, all of work environment monitoring data measured by industrial hygiene laboratories were mandatorily reported to the KOSHA. Although the KOSHA data were collected for 3 years only, it has the most diverse exposure groups belonging to 58 types of industry. Among them, 38% of exposure groups (22 of 58) were related to handling talc containing asbestos and these groups also include the highest WAM concentration of 2.45 f/mL, belonging to the exposure value from the manufacturing of surface-active agents (KSIC code: 20431). Exposure to talc has been suggested as a causative factor in the development of ovarian carcinomas and mesothelioma [24–26]. In 2009, there was a big issue about talc powder for babies contaminated with asbestos, presumably from the manufacturing process in the Republic of Korea [27]. According to the Korea Food and Drug Administration survey, 1,122 drugs and medical goods have been confirmed to contain talc contaminated with asbestos.

All of data used in this study were directly related to work characteristics such as handling material, operation of machine, and process and we did not consider other sources of asbestos that may contribute to the magnitude of exposure. For instance, if workers have worked in buildings under old roofs constructed from asbestos slate materials, they can also be exposed to airborne asbestos fibers released from slate and this could change the scenario and magnitude of asbestos exposure. This and other possible environmental sources of asbestos that may affect asbestos exposure should be considered. Future studies with environmental exposure data will be needed to estimate the additional effects of environmental exposure.

Regarding the number of samples, the number of analyzed samples was not evenly distributed across industries. For the GSPH-SNU database, 51.3% of data (1,089 of 2,124) were collected from automobile parts assemblers (KSCO code: 85429) working at industries manufacturing parts and accessories for motor vehicles and engines (KSIC code: 303). In terms of the KOSHA database, 67.3% of data (1,926 of 2,862) were measured among elementary workers in construction (KSIC code: 91001) that are involved with dismantling asbestos of buildings. Furthermore, some exposure groups had no information on the number of samples (EG04 and EG11) or had only one sample (EG31, EG52, and EG80) that resulted in under-representation on the constructed GPJEM for asbestos in the Republic of Korea.

The GPJEM constructed in this study provides quantified estimates of asbestos exposure levels for 112 Korean exposure groups classified under 86 industries and 74 occupations from 1984 to 2008. Despite several limitations, this GPJEM could be very useful in the evaluation of the contribution of asbestos exposure on the prediction of ARD occurrence as influenced by the patients' historical exposure. The strength of the constructed GPJEM relied more on the fact that database sources were based on domestic quantitative exposure data covering the major industries in the Republic of Korea.

Conflicts of interest

All authors have no conflicts of interest to declare.

Acknowledgments

This research was supported by the research grants from Catholic University of Daegu in 2015. The authors specially express their thanks to Dr Venecio Ultra at Catholic University of Daegu for helping with English editing and comments.

References

- [1] International Agency for Research on Cancer (IARC). IARC Monographs Volume 100C: Arsenic, metals, fibres and dusts; a review of human carcinogens [Internet]. 2012 [cited 2016 Jun 3]. Available from: <http://monographs.iarc.fr/ENG/Monographs/vol100C/mono100C.pdf>.
- [2] World Health Organization. Elimination of asbestos-related diseases [Internet]. 2006 [cited 2016 Jun 3]. Available from: http://whqlibdoc.who.int/hq/2006/WHO_SDE_OEH_06.03_eng.pdf?ua=1.
- [3] World Health Organization. Chrysotile asbestos [Internet]. 2014 [cited 2016 Jun 3]. Available from: http://www.who.int/ipcs/assessment/public_health/chrysotile_asbestos_summary.pdf.
- [4] United States Geological Survey. 2013 Minerals yearbook: asbestos [Internet]. 2014 [cited 2016 Jun 3]. Available from: <http://minerals.usgs.gov/minerals/pubs/commodity/asbestos/myb1-2013-asbes.pdf>.
- [5] Park D, Choi S, Ryu K, Park J, Paik N. Trends in occupational asbestos exposure and asbestos consumption over recent decades in Korea. *Int J Occup Environ Health* 2008;14:18–24.
- [6] Takahashi Y, Miyaki K, Nakayama T. Analysis of news of the Japanese asbestos panic: a supposedly resolved issue that turned out to be a time bomb. *J Public Health (Oxf)* 2007;29:62–9.
- [7] Nishikawa K, Takahashi K, Karjalainen A, Wen C, Furuya S, Hoshuyama T, Todoroki M, Kiyomoto Y, Wilson D, Higashi T, Ohtaki M, Pan G, Wagner G. Recent mortality from pleural mesothelioma, historical patterns of asbestos use, and adoption of bans: a global assessment. *Environ Health Perspect* 2008;116:1675–80.
- [8] Brims FJ. Asbestos—a legacy and a persistent problem. *J R Nav Med Serv* 2009;95:4–11.
- [9] Choi S, Suk MH, Paik NW. Asbestos-containing materials and airborne asbestos levels in industrial buildings in Korea. *J UOEH* 2010;32:31–43.
- [10] Seixas NS, Robins TG, Moulton LH. The use of geometric and arithmetic mean exposures in occupational epidemiology. *Am J Ind Med* 1988;14:465–77.
- [11] Aitchison J, Brown J. *The lognormal distribution*. Cambridge (UK): Cambridge University Press; 1963. 8 p.
- [12] Park D, Stewart PA, Coble JB. A comprehensive review of the literature on exposure to metalworking fluids. *J Occup Environ Hyg* 2009;6:530–41.
- [13] National Institute of Labor Science. Investigation of hazard environment of asbestos industry. Seoul, Republic of Korea: Ministry of Labor of Korea; 1984. [in Korean].
- [14] Park DY, Paik NW. Worker exposure to asbestos fibers in asbestos slate manufacturing and asbestos textile industries. *Kor J Env Health Soc* 1988;14:13–27. [in Korean].
- [15] Paik NW. Worker exposure to asbestos in Korean asbestos industries. *Korean J Pub Health* 1989;42:115–21. [in Korean].
- [16] Paik NW, Lee YH. Characterization of worker exposure to airborne asbestos in asbestos industry. *Korean Ind Hyg Assoc J* 1991;1:144–53. [in Korean].
- [17] Park JI, Yoon CS, Paik NW. A study on exposure among asbestos textile workers and estimation of their historical exposures. *Korean Ind Hyg Assoc J* 1995;5:16–39. [in Korean].
- [18] Oh SM, Shin YC, Park DY, Park DU, Chung KC. A study on worker exposure level and variation to asbestos in some asbestos industries. *Korean Ind Hyg Assoc J* 1993;3:100–9. [in Korean].
- [19] Choi JK, Paek D, Paik NW. The production, the use, the number of workers and exposure level of asbestos in Korea. *Korean Ind Hyg Assoc J* 1998;8:242–53. [in Korean].
- [20] Kauppinen T, Toikkanen J, Pukkala E. From cross-tabulations to multipurpose exposure information systems: a new job-exposure matrix. *Am J Ind Med* 1998;33:409–17.
- [21] Peters S, Vermeulen R, Cassidy A, Mannetje A, van Tongeren M, Boffetta P, Straif K, Kromhout H; INCO Group. Comparison of exposure assessment methods for occupational carcinogens in a multi-centre lung cancer case-control study. *Occup Environ Med* 2011;68:148–53.
- [22] van Oyen SC, Peters S, Alfonso H, Fritsch L, de Klerk NH, Reid A, Franklin P, Gordon L, Benke G, Musk AW. Development of a job-exposure matrix (AsbjEM) to estimate occupational exposure to asbestos in Australia. *Ann Occup Hyg* 2015;59:737–48.
- [23] National Institute for Occupational Safety and Health (NIOSH). Asbestos and other fibers by PCM, Method 7400, NIOSH manual of analytical methods. [Internet]. 4th ed., Cincinnati (OH); 1994 [cited 2016 Jun 2]. Available from: <http://www.cdc.gov/niosh/docs/2003-154/pdfs/7400.pdf>.

- [24] Gordon RE, Fitzgerald S, Millette J. Asbestos in commercial cosmetic talcum powder as a cause of mesothelioma in women. *Int J Occup Environ Health* 2014;20:318–32.
- [25] Heller DS, Gordon RE, Katz N. Correlation of asbestos fiber burdens in fallopian tubes and ovarian tissue. *Am J Obstet Gynecol* 1999;181:346–7.
- [26] Heller DS, Westhoff C, Gordon RE, Katz N. The relationship between peritoneal cosmetic talc usage and ovarian talc particles burden. *Am J Obstet Gynecol* 1996;174:1507–10.
- [27] Kim HR. Overview of asbestos issues in Korea. *J Korean Med Sci* 2009;24:363–7.