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Original Article

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

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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.
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## 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

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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 9$^{th}$ 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 6$^{th}$ 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]:

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

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 ($\widehat{\mu}_L$); second, the range of the log transformed levels divided by four provided an estimate of the standard deviation of the log transformed levels ($\widehat{\sigma}_L$); and finally, AM was calculated using the following formula (2):

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

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).

$$\mathrm{WAM} = (\mathrm{N}_1 \times \mathrm{AM}_1 + \mathrm{N}_2 \times \mathrm{AM}_2 + \cdots + \mathrm{N}_n \times \mathrm{AM}_n)/\mathrm{N}_t \quad (3)$$

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 (KSIC 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 (KSIC 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 | 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 hammersmiths and forging press workers | NI | 2 | 0.0075 | 0.005 | 0.01 |
| EG46 | 1995 | 22232 | Manufacture of packaging plastics and shipping containers | 83231 | Plastic catapulting 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 (KSIC 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 | | | | | | |
| 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 unvulcanized 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 (KSIC 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.

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