Reconstruction of the Korean Asbestos Job Exposure Matrix

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ABSTRACT

Background: A job-exposure matrix (JEM) is an important surrogate indicator to evaluate past exposure levels. Although a Korean asbestos JEM has been constructed previously, this JEM includes only a few industrial and occupational groups. This study aimed to reconstruct the JEM by integrating the latest organized data to improve its utility.

Methods: We used recent Korean standard industry and occupation codes and extracted 36 articles from a systematic literature review to initiate the reconstruction of the previous Korean asbestos JEM. The resulting data consisted of 141 combinations of industrial and occupational groups. Data from the Netherlands’s JEM were also reviewed and categorized into 70 industrial and 117 occupational groups by matching with the Korean data. We also utilized Germany’s data, which consisted of 10 industrial and 14 occupational groups.

Results: The reconstructed Korean asbestos JEM had 141 combinations of industries and occupations. The time periods are from the 1980s to the 2000s in 10-year intervals. Most of the data were distributed between the 1990s and the 2000s. Occupations with high exposure to asbestos included knitting and weaving machine operators, automobile mechanics or assemblers, ship mechanics or assemblers, mineral ore and stone products processing mechanics, and metal casting machine operators or mold makers.

Conclusions: The reconstructed Korean asbestos JEM has expanded the type and duration of the occupational groups of the previous JEM and can serve as an important reference tool for evaluating asbestos exposure and designing compensation and prevention policies in Korea.

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1. Introduction

Asbestos is a group of natural fibrous silicate minerals that are resistant to heat, fire, corrosion, and electricity. Because of these properties, it has been globally used in industry. As asbestos continues to be used for decades, there have been growing concerns about its health effects, and studies on occupational and environmental exposure to the compound have been conducted. Asbestos is known to cause asbestos-related diseases (ARDS), such as malignant mesothelioma, lung cancer, laryngeal cancer, ovarian cancer, asbestososis, and pleural disease (pleural plaque and pleural thickening) [1]. Asbestososis was first recognized in the 1930s, lung cancer in the 1950s, and malignant mesothelioma in the 1960s [2]. The International Agency for Research on Cancer classified asbestos as a group 1 carcinogen [3]. ARDs have a dose–response relationship, with a long latency between exposure and disease. ARDs, including asbestosis and cancers, have a minimum latency period of 10 years. Therefore, the estimation of past exposure before the onset of the disease is important to clarify the association between the exposure and the disease [4]. However, direct exposure assessment has limitations due to time, technical, and spatial constraints [5]. As a countermeasure, a job-exposure matrix (JEM) can be used as a tool for assessing past exposure levels.

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A JEM is designed to link information on occupation and exposure to specific workplace hazards [6]. It was first introduced in 1941 [7] and has been used extensively in occupational epidemiological studies since the 1980s [8]. The advantage of using a JEM is that it reduces a differential information bias using standardized industry/job titles in certain circumstances such as case–control studies between cases and controls [9].

In Korea, asbestos imports have increased since the 1970s and began to be used in various occupations as industrialization started. The Saemaeul movement was one of the national programs of industrialization. As a new town program of the movement, the thatched roofs in rural area were replaced with slate roofs made by asbestos. As the exposure to asbestos increased and the asbestos-related health problem had been emerged, studies began to be performed after the 1980s, leading to the first compensation case for ARDs in 1993. Data on asbestos exposure at the time were limited, and this led to the construction of the Korean asbestos JEM [10]. Other countries such as the Netherlands and Germany also developed their own JEM. However, the Korean asbestos JEM remained limited in terms of data. This study aims to reconstruct the previous Korean asbestos JEM by integrating recent Korean data and data from the Netherlands’ and Germany’s JEM to improve the utility of the tool.

2. Materials and methods

To reconstruct the previous asbestos JEM, we combined the previous asbestos general population JEM (GPJEM), a systematic literature review, and extracted the Netherlands’ and Germany’s JEM data and showed it to the reconstructed Korean asbestos JEM for comparison (Fig. 1). Finally, the reconstructed asbestos JEM was composed of 141 combinations of industrial and occupational groups.

2.1. Korean measurement data

We referred to the most recently published GPJEM. The data resource of the GPJEM is composed of the Korean literature from 1984 to 1996, the Graduate School of Public Health Seoul National University database, which contains the exposure information between 1995 and 2006, and the Korean Occupational Safety and Health Agency database between 2005 and 2008 [10].

2.2. The systematic literature review

In addition, a systematic literature review of Korean and international databases was performed.

2.2.1. Inclusion criteria

- Any literature about asbestos exposure levels in the workplace, including abstracts, journal articles, books, conference papers, related publications, and related conferences

Fig. 1. Composition of data for new construction of the asbestos JEM.

Fig. 2. Flow of the systemic literature review and data extraction.
- The search terms were “asbestos” and “Korea” for until 2017 in Korea.
- Any literature or abstract published in Korean or English

2.2.2. Search databases
- Research Information Sharing Service (www.riss.kr)
- Google Scholar (http://scholar.google.co.kr/)

2.2.3. Review process
An information retrieval strategy was used, and duplicate articles were excluded. The final selection was performed in two steps: exclusion of the article after reviewing the title and abstract and exclusion of the article after reading the full text.

2.2.4. Data extraction
Among 76 articles selected in the systematic literature review, 26 were excluded because of overlap between the measured data and other data, and 14 were excluded because of absence of information on the time period. Finally, we analyzed 36 articles and used the obtained data of the weighted arithmetic mean for the reconstruction of the previous Korean asbestos JEM. A flow chart of the literature inclusion process is shown in Fig. 2.

2.3. The asbestos JEM of other countries

2.3.1. The Netherlands’ data
We gathered data from the Netherlands’ JEM based on the study of Swuste et al [12] to reconstruct the Korean asbestos JEM. The data consisted of 70 industries, 309 occupations, and a total exposure period of 50 years, from 1945 to 1994, divided into five-year intervals. We converted these data into 70 industries and 91 occupations with the same periods by matching the Standard Industry Codes and Standard Classification of Occupations codes based on International Standard Classification of Occupations 88 (ISCO-88) with Korean codes based on ISCO-88. We used the website http://www.asbestkaart.nl by the Asbestos Victims Institute, which offers raw data of asbestos exposure [13], and finally classified the Netherlands’ industrial and occupational categories into 70 industrial and 117 occupational groups and an additional seven subcategories. For these matched data, we assigned the Netherlands’ ID by arranging the codes based on the 10th Korea Standard Industry Code (KSIC) and the 7th Korea Standard Classification of Occupations (KSOC). The exposure level was divided into seven codes: “0,” no exposure; “a,” 0–0.5 fibers/cm³; “b,” 0.5–1 fibers/cm³; “c,” 1–2 fibers/cm³; “d,” 2–5 fibers/cm³; “e,” 5–10 fibers/cm³; and “f,” ≥10 fibers/cm³.

2.3.2. Germany’s data
For data from Germany’s JEM, we referred to the BK-Report 1/2013 Faserjahre [14] and converted German Standard Industry Codes and Standard Classification of Occupations codes into Korean codes. After translating German to Korean, we matched the German JEM data with appropriate KSIC and KSOC categories. Exposure levels were included in the reconstructed JEM.

2.3.3. Listing of the Netherlands and German JEM in the Korean asbestos JEM table
We extracted 84 combinations of the Netherlands’ JEM data and 11 combinations of Germany’s JEM data. Among them, we represented the matched 49 Netherlands’ data and six Germany’s JEM data with the most similar combination of Korean JEM data.

### Table 1

| Exposure groups | 1980 | 1990 | 2000 |
|-----------------|------|------|------|
| E1              | 6(42.9) | 5(9.3) | 6(51.5) |
| E2              | 7(50.0) | 7(13.0) | 31(26.5) |
| E3              | 0(0.0)  | 28(51.9) | 34(29.1) |
| E4              | 1(7.1)  | 14(25.9) | 46(39.3) |
| Total           | 14(100) | 54(100) | 117(100) |

E1: ≥1 fibers/cm³; E2: 0.1–1 fibers/cm³; E3: 0.01–0.1 fibers/cm³; and E4: <0.01 fibers/cm³.

3. Results

For Korean data, we designated the exposure level into four categories: E1, ≥1 fibers/cm³; E2, 0.1–1 fibers/cm³; E3, 0.01–0.1 fibers/cm³; and E4, <0.01 fibers/cm³. The number of industrial and occupational combinations (IOCs) was 14 in the 1980s, which increased to 54 in the 1990s and 117 in the 2000s. The number of occupational groups with a highly exposed level (E1) was six (42.9%) in 1980s, five (9.3%) in 1990s, and six (5.1%) in 2000s. (Table 1). The proportions of over 0.1 f/cc that was the current occupational exposure limit of Korea were the highest as 92.9% in the 1980s, then decreased to 22.3% in the 1990s, and was 31.6% in 2000s.

A newly constructed asbestos JEM table for 141 IOCs was established (Table 2). There were the industrial code and name (the 10th KSIC) of 2017, which was relevant to ISCO-88 and the occupational code and name (the 7th KSOC) of 2017. The concentrations of asbestos were represented for three periods, the 1980s, 1990s, and 2000s. There were three IOCs which contains concentration data in 2010s, and they were added in the 2000s tab. It also contains estimated exposure values and levels to compare data from the Netherlands’ and Germany’s JEM. Netherlands’ data and Germany’s data were added to the most relevant combination of industry and occupation for comparison.

The list of IOCs with the highest exposure level (E1) by years is provided in Table 2. In the 1980s, they were grinding and mixing machine operators of the asbestos mining industry (IOC 2), textile production and processing machine operators of the asbestos textile industry (IOC 48), machine operators of the asbestos (cement) industry (IOC 52), metal casting machine operators of the iron and steel industry (IOC 56), ship assemblers of the ship industry (IOC 91), and store salespersons of motor vehicle parts and accessories (IOC 110). In the 1990s, highly exposed groups were weaving machine operators of fiber fabrics (IOC 6), machine operators of wood and paper (IOC 15), plastic products (IOC 34), the asbestos textile industry (IOC 48), and automobile mechanics of repair services of motor vehicles (IOC 139). In the 2000s, highly exposed groups were paper products machine operators (IOC 10), painting machine operators of manufacture of paperboard boxes and containers (IOC 13), grinding and mixing machine operators of synthetic resin and other plastic materials (IOC 19), machine operators of surface-active agents (IOC 24), construction stonemasons (IOC 43), and automobile paint mechanics (IOC 87). All E1 occupations in the 2000s were jobs handling talc-containing asbestos. Asbestos textile processing operation (IOC 48) had the highest exposure level, 7.46 f/cc in the 1980s and in Netherlands’ with a peak of 5–10 f/cc from the 1940s to 1960s.

4. Discussion

This study aimed to construct a new Korean asbestos JEM by comparing data from the Netherlands’ and Germany’s JEM, which led to the expansion of the previous JEM to 141 combinations of...
Table 2
The newly constructed asbestos JEM.

| IOC numbers | Industry (KSIC, 10th) Code | Name | Occupation (KSOC, 7th) Code | Name | Exposure or sampling description | Concentration (f/cc) | References | The Netherlands (NL), Germany (DE) data |
|-------------|---------------------------|------|---------------------------|------|----------------------------------|----------------------|-----------|-----------------------------------------|
| 1           | 07290                     | Mining of Other Non-metal Ores n.e.c. 91002 | Mining Laborers | Asbestos mining | 0.235 | Moon, 1979 [21] |
| 2           | 07290                     | Mining of Other Non-metal Ores n.e.c. 83121 | Chemical Material Grinding and Mixing Machine Operators | Asbestos grinding mill | 2.94 | Moon, 1979 [21] |
| 3           | 07290                     | Mining of Other Non-metal Ores n.e.c. 78412 | Quarrymen | | 0.006 | Yoon, 2011 [38] |
| 4           | 10301                     | Processing and Preserving of Fruit and Vegetables, Pickled Food 71052 | Side Dish Makers | | 0.013 | Choi, 2006 [32] |
| 5           | 13102                     | Spinning of wool 8211 | Textile Processing Machine Operators | Handling talc-containing asbestos | 0.74 | KOSHA DB |
| 6           | 13213                     | Weaving of Man-Made Fiber Fabrics 82211 | Weaving Machine Operators | | 1.52 | SNU DB |
| 7           | 13993                     | Manufacture of Special Yarns and Tire Cord Fabrics 8211 | Textile Processing Machine Operators | | 0.073 | SNU DB |
| 8           | 15219                     | Manufacture of Other Footwear 721 | Textile and Leather Related Workers | Area sampling in factory building construction with asbestos-containing material | 0.026 | KOSHA DB |
| 9           | 17129                     | Manufacture of Other Paper and Paperboard 89132 | Paper Machine Operators | Handling talc-containing asbestos | 0.810 0.009 0.005 | SNU DB |

(continued on next page)
| IOC numbers | Industry (KSIC, 10th) | Occupation (KSOC, 7th) | Exposure or sampling description | Concentration (f/cc) | References | The Netherlands (NL), Germany (DE) data |
|-------------|----------------------|------------------------|---------------------------------|----------------------|------------|--------------------------------------|
| 10          | 17129                | Manufacture of Other Paper and Paperboard | 8914 Paper products production machine operators Handling talc-containing asbestos | 1.61 | KOSHA DB | 19(Manufacture of Coke, hard-coal and lignite fuel briquettes and Refined Petroleum Products) and 21332(Chemisty Technicians): 0–0.5 (1945–1984) (NL) |
| 11          | 17221                | Manufacture of Paper Sacks and Paper Bags | 84219 Painting Machine Operators n.e.c. | 0.113 | KOSHA DB | |
| 12          | 17222                | Manufacture of Paperboard Boxes and Containers | 89141 Box and Envelope Making Machine Operators | 0.452 | KOSHA DB | |
| 13          | 17222                | Manufacture of Paperboard Boxes and Containers | 84219 Painting Machine Operators n.e.c. Handling talc-containing asbestos | 1.51 | KOSHA DB | |
| 14          | 17902                | Manufacture of Sanitary Paper Products | 89144 Sanitary Paper Products Machine Operators | 0.116 | KOSHA DB | |
| 15          | 17909                | Manufacture of Other Articles of Paper and Paperboard n.e.c. | 89190 Wood and Paper Related Machine Operators n.e.c. | 3.544 | SNU DB | |
| 16          | 20111                | Manufacture of Basic Organic Petrochemicals | 83219 Chemical Products Production Machine Operators n.e.c. | 0.010 | SNU DB | 19(Manufacture of Coke, hard-coal and lignite fuel briquettes and Refined Petroleum Products) and 21332(Chemistry Technicians): 0–0.5 (1945–1984) (NL) |
| 17          | 424                  | Interior and Building Completion | 7824 Construction Carpenters | 0.012 | KOSHA DB | 311(Building of Ships and Boats) and 7824(Construction Carpenters): production of asbestos plaster, sealant production 1–2 (1945–1974), 0.5–1 (1975–1979), 0–0.5 (1980–1994) (NL) |
| 18          | 2030                | Manufacture of Synthetic Rubber and of Plastics in Primary Forms | 8312 Chemical Material Processing Machine Operators Manufacturing of synthetic resin | 0.113 | KOSHA DB | |
| 19          | 20302               | Manufacture of Synthetic Resin and Other Plastic Materials | 83121 Chemical Material Grinding and Mixing Machine Operators Handling talc-containing asbestos | 1.06 | KOSHA DB | |
| 20          | 20302               | Manufacture of Synthetic Resin and Other Plastic Materials | 83124 Chemical Material Distiller and Reactor Operators Handling talc-containing asbestos | 0.73 | KOSHA DB | |
| 21          | 20302               | Manufacture of Synthetic Resin and Other Plastic Materials | 84219 Painting Machine Operators n.e.c. Handling talc-containing asbestos | 0.690 | KOSHA DB | |
22 20302 Manufacture of Synthetic Resin and Other Plastic Materials 83239 Plastic Products Production Machine Operators n.e.c. Mixing of epoxy resin 0.861 0.043 0.043 SNU DB

23 20421 Manufacture of General Paints and Similar Products 83121 Chemical Material Grinding and Mixing Machine Operators Manufacturing of paint 0.619 KOSHA DB

24 20431 Manufacture of Surface-Active Agents 83213 Detergents Production Machine Operators Handling talc-containing asbestos 2.45 KOSHA DB

25 20493 Manufacture of Adhesives and Gelatin 83121 Chemical Material Grinding and Mixing Machine Operators Handling talc-containing asbestos 0.055 KOSHA DB

26 20499 (20111) Manufacture of All Other Chemical Products n.e.c. 83219 Painting Machine Operators n.e.c. 0.010 SNU DB

27 21300 Manufacture of Pharmaceutical Goods Other Than Medicaments 83211 Pharmaceutical Products Production Machine Operators 0.016 SNU DB

28 221 Manufacture of Rubber Products 83239 Plastic Products Production Machine Operators n.e.c. 0.110 KOSHA DB

29 22111 Manufacture of Tires and Tubes 83221 Tire Production Machine Operators Handling talc-containing asbestos 0.658 KOSHA DB

30 22191 Manufacture of Industrial Un-vulcanized Rubber Products 83229 Tire and Rubber Products Production Machine Operators Handling talc-containing asbestos 0.961 KOSHA DB

31 22199 Manufacture of Other Rubber Products n.e.c. 83222 Rubber Products Production Machine Operators n.e.c. 0.012 0.012 SNU DB

32 20301 Manufacture of Synthetic Rubber 83222 Rubber Products Production Machine Operators Handling talc-containing asbestos 0.468 KOSHA DB

33 22232 Manufacture of Packaging Plastics and Shipping Containers 83231 Plastic Catapulting Machine Operators 0.008 SNU DB

34 22250 Manufacture of Foamed Plastic Products 83239 Plastic Products Production Machine Operators 5.12 SNU DB

(continued on next page)
| IOC numbers | Industry (KSIC, 10th) | Occupation (KSOC, 7th) | Exposure or sampling description | Concentration (f/cc) | References | The Netherlands (NL), Germany (DE) data |
|-------------|------------------------|------------------------|----------------------------------|----------------------|-----------|---------------------------------------|
| 35          | 22299                  | Manufacture of Other Plastic Products n.e.c. | Plastic Products Production Machine Operators n.e.c. | 0.012 0.012 | SNU DB | 2229-Manufacture of Other Plastic Products): asbestos gaskets, electric isolation. 1 – 2 (1945 – 1969), 0.5 – 1 (1970 – 1974), 0 – 0.5 (1975 – 1994) (NL) |
| 36          | 20302                  | Manufacture of synthetic resin and other plastic materials | Plastic Products Production Machine Operators n.e.c. | Manufacturing of brake lining | 0.043 0.043 | SNU DB |
| 37          | 23199                  | Manufacture of All Other Glass and its Products n.e.c. | Glass and Glass Products Machine Operators n.e.c. | Working around mercury filling and air vent machines | 0.007 | KOSHA DB |
| 38          | 23211                  | Manufacture of Pottery and Ceramic Household or Ornamental Ware | Pottery and Porcelain Products Production Machine Operators n.e.c. | | 0.006 | KOSHA DB |
|             | 23229                  | Manufacture of Other Refractory Ceramic Products | Glass and Glass Products Machine Operators n.e.c. | | 0.064 | Choi, 2006 [32] |
| 39          | 23229                  | Manufacture of Other Refractory Ceramic Products | Brick and tile molding machine operators | | 0.0642 | SNU DB |
|             | 23324                  | Manufacture of Celulose Fiber Cement Products | Cement and Lime Production Related Machine Operators | Extruding molding of cement | 0.013 | KOSHA DB |
| 40          | 23325                  | Manufacture of Concrete Roofing Tiles, Bricks and Blocks | Brick and Tile Production Machine Operators | | 0.059 | Choi, 2006 [32] |
| Page | Code | Activity | Industry | Occupation | Asbestos Exposure | Notes |
|------|------|----------|----------|------------|------------------|-------|
| 43   | 2391 | Cutting, Shaping and Finishing of Stone | 78230 | Construction Stonemasons | Handling talc-containing asbestos | 1.18 KOSHA DB | 311(Building of Ships and Boats) and 7824(Construction Carpenters): Production of asbestos plaster, sealant production. 12(1945–1974), 0.5–1(1975–1979), 0–0.5(1980–1994) (NL) |
| 44   | 23911 | Manufacture of Stone Products for Construction | 84341 | Mineral Ore and Stone Processing Machine Operators | Manufacturing of asbestos slates | 0.46 0.74 0.145 Paik, 1989 [23] Paik, 1991 [24] Oh, 1993 [25] Park, 1995 [27] Choi, 1998 [29] | 23911 (Manufacture of Stone Products for Construction) and 93001(Packing Laborers): 2–5 (1945–1969), 1–2 (1970–1974), 0.5–1 (1975–1979), 0–0.5 (1980–1994) (NL) 23911 (Manufacture of Stone Products for Construction) and 141 (Construction, Electricity and Production Related Managers): 1–2(1945–1974), 0–0.5(1975–1994), (NL) |
| 45   | 23919 | Manufacture of Other Stone Products | 78230 | Construction Stonemasons | | 0.400 Choi, 2006 [32] |
| 46   | 23992 | Manufacture of Abrasive Articles | 84392 | Brightener Production Machine Operators | | 0.807 0.56 Choi, 2006 [32] SNU DB |
| 47   | 7121 | Quarrying of Monumental and Building Stone | 84341 | Mineral Ore and Stone Processing Machine Operators | | 0.912 Yoon, 1993 [41] |
| 48   | 23994 | Manufacture of Asbestos, Mineral Wools and Other Similar Products | 821, 8221 | Textile Production and Processing Machine Operators | Manufacturing of asbestos textile, knitting and waving machine operators | 7.48 2.55 0.14 Choi, 2006 [32] Lim, 1999 [42] KOSHA DB | 13213(Weaving of Man-Made Fiber Fabrics) and 8211(Textile Processing Machine Operators): 5–10 (1945–1969), 2–5 (1970–1974), 0.5–1 (1975–1984), 0–0.5 (1985–1994) (NL) 13213(Weaving of Man-Made Fiber Fabrics) and 8221(Knitting and Weaving Machine Operators): 5–10 (1945–1969), 2–5 (1970–1974), 0.5–1 (1975–1984), 0–0.5 (1985–1994) (NL) |

(continued on next page)
| IOC numbers | Industry (KSIC, 10th) | Occupation (KSOC, 7th) | Exposure or sampling description | Concentration (f/cc) | References | The Netherlands (NL), Germany (DE) data |
|-------------|-----------------------|------------------------|----------------------------------|----------------------|------------|---------------------------------------|
| 50          | 23994 Manufacture of Asbestos, Mineral Wools and Other Similar Products | 84159 Metal Processing Machine Operators n.e.c. |  | 0.025 | Jung, 1994 [26] | 13993 (Manufacture of Special Yarns and Tire Cord Fabrics) and Administrative and management support managers, n.e.c.: Asbestos textile industry, other production activities, asbestos insulation pipeline production/office management/indirect exposure pollution 1–2 (1945–1974); 0.5–1 (1975–1979), 0–0.5 (1980–1994) (NL) |
| 51          | 23994 Manufacture of Asbestos, Mineral Wools and Other Similar Products | 84322 Brick and Tile Production Machine Operators |  | 0.03 | SNU DB | |
| 52          | 23994 Manufacture of Asbestos, Mineral Wools and Other Similar Products | 8433 Cement and Mineral Products Production Machine Operators | Manufacturing of asbestos gaskets | 1.7 | 0.78 | 0.018 | Choi, 2017 [10] | KOSHA DB |
| 53          | 23999 Manufacture of Other Unclassified Nonmetallic Minerals n.e.c. | 84399 Nonmetal Products Related Production Machine Operators n.e.c. |  | 0.069 | 0.069 | SNU DB | |
| 54          | 24119 (24111) Manufacture of Other Basic Iron and Steel (Manufacture of Basic Iron) | 84141 Ore and Metal Furnace Operators |  | 0.008 | 0.008 | SNU DB | |
| 55          | 24121 Manufacture of Hot Rolled, Drawn and Extruded Iron or Steel Products | 84151 Rolling Mill Operators |  | 0.04 | 0.04 | SNU DB | |
| 56          | 2431 Cast of Iron and Steel | 84110 Metal Casting Machine Operators | Welding with asbestos cloth | 1.54 | Paik, 1989 [23] | |
| 57          | 25119 Manufacture of Other Structural Metal Products | 84213 Metal Product Painting Machine Operators |  | 0.211 | KOSHA DB | |
| Page | Code | Description | NAICS Code | Task | Exposure Value | Database |
|------|------|-------------|-------------|------|----------------|----------|
| 58   | 25911 (25999) | Manufacture of Powder Metallurgic Products | 84159 | Melting of metal powders | 0.003 | KOSHA DB |
|      |      |              |            |      |                |          |
|      |      |              |            |      |                |          |
| 59   | 25912 (24) |Forging of Metal/ Manufacture of Basic Metal Products | 74130 | Forge Hammer smiths and Forging Press Workers | 0.008 | KOSHA DB |
|      |      |              |            |      |                |          |
|      |      |              |            |      |                |          |
| 60   | 25913 | Manufacture of Metal Pressed and Stamped Products | 84151 | Rolling Mill Operators | 0.007 | SNU DB |
|      |      |              |            |      |                |          |
|      |      |              |            |      |                |          |
| 61   | 25921 | Heat Treatment of Metals | 84155 | Metal Heat Treatment Furnace Operators | 0.034 | KOSHA DB |
|      |      |              |            |      |                |          |
|      |      |              |            |      |                |          |
| 62   | 25923 | Coating and Similar Treatment of Metals | 84229 | Plating and Metal Spraying Machine Operators n.e.c. | 0.117 | KOSHA DB |
|      |      |              |            |      |                |          |
|      |      |              |            |      |                |          |
| 63   | 25934 | Manufacture of Saws, Saw Blades and Interchangeable Tools | 74110 | Die and Mold Makers | 0.009 | SNU DB |
|      |      |              |            |      |                |          |
|      |      |              |            |      |                |          |
| 64   | 26299 | Manufacture of Other Electronic Valves, Tubes and Electronic Components n.e.c. | 86321 | Electronic Parts Production Equipment Operators | 0.011 | SNU DB |
|      |      |              |            |      |                |          |
|      |      |              |            |      |                |          |
| 65   | 2642 | Manufacture of Broadcasting and Wireless Telecommunication Apparatuses | 86409 | Electrical, Electronic Parts and Products Assembler n.e.c. | 0.028 | SNU DB |
|      |      |              |            |      |                |          |
|      |      |              |            |      |                |          |
| 66   | 26529 | Manufacture of Other Sound Equipment | 86402 | Audio-Visual Equipment Assemblers | 0.022 | SNU DB |
|      |      |              |            |      |                |          |
|      |      |              |            |      |                |          |
| 67   | 27216 | Manufacture of Industrial Process Control Equipment | 76224 | Electrical Control Unit Fitters and Mechanics | 0.001 | KOSHA DB |
|      |      |              |            |      |                |          |
|      |      |              |            |      |                |          |

(continued on next page)
| IOC numbers | Industry (KSIC, 10th) | Occupation (KSOC, 7th) | Exposure or sampling description | Concentration (f/cc) | References | The Netherlands (NL), Germany (DE) data |
|-------------|------------------------|------------------------|---------------------------------|---------------------|------------|--------------------------------------|
| 68          | 27216 Manufacture of Industrial Process Control Equipment | 85101 Lathe Machine Operators | Operation of milling machines for electromagnetic clutches | 0.002 | KOSHA DB |                                 |
| 69          | 28111 Manufacture of Electric Motors and Generators | 86401 Electrical Equipment Assemblers | | 0.014 0.072 | Choi, 2006 | SNU DB |
| 70          | 28119 Manufacture of Other Electric Motors, Generators and Transformers | 85109 Metal Work Machinery Operators n.e.c. | | 0.065 0.075 | Lee, 2013 [40] | |
| 71          | 28119 Manufacture of Other Electric Motors, Generators and Transformers | 8610, 86311 Power Generation and Distribution Equipment Operators, Electrical Parts Production Equipment Operators | Manufacturing of rotary machine parts | 0.004 | Choi, 2006 [32] | KOSHA DB |
| 72          | 28302 Manufacture of Other Insulated Wire and Cable | 86402 Audio-Visual Equipment Assemblers | | 0.358 | KOSHA DB | 2811 (Manufacture of Electric Motors, Generators and Transformers) and thermal power plant operators: 3.33, 3.55, 8.88, 1.11 (1956–1974) (DE) |
| 73          | 28303 Manufacture of Insulated Codes Sets and Other Conductors for Electricity | 86401 Electrical Equipment Assemblers | Extrusion of electric cables | 0.125 | KOSHA DB | 28302 (Manufacture of Other Insulated Wire and Cable) and 141 (Construction, Electricity and Production Related Managers): 1–2 (1945–1974), 0–0.5 (1975–1994) (NL) |
| 74          | 28410 Manufacture of Electric Lamps and Electric Bulbs | 86312 Electrical Products Production Equipment Operators | Manufacturing lamps for cars | 0.203 | KOSHA DB | |
| 75          | 28422 Manufacture of General Electric Lighting Fixture | 86401 Electrical Equipment Assemblers | Manufacturing of general lamps | 0.020 | KOSHA DB | |
| 76          | 28519 Manufacture of Other Domestic Electric Appliances | 86312 Electrical Products Production Equipment Operators | | 0.005 | SNU DB | |
| 77          | 29132 Manufacture of Pumps and Compressors | 88904 Air Compressor Operators | | 0.005 | SNU DB | |
| 78          | 29133 Manufacture of Taps, Valves and Similar Products | 8510 Metal Work Machinery Operators | | 0.556 | KOSHA DB | |
| Code | Description | NAICS Code | Occupation | Exposure to Asbestos |
|------|-------------|------------|------------|-------------------|
| 79   | Manufacture of Other Work trucks, Lifting and Handling Equipment | 8544 | General Machinery Assemblers | 0.009
| 80   | Manufacture of Agricultural and Forestry Machinery | 83239 | Plastic Products Production Machine Operators n.e.c. | 0.003
| 81   | Manufacture of Agricultural and Forestry Machinery | 85442 | Agricultural Machinery Assemblers | 0.046
| 82   | Manufacture of Machinery for Food, Beverage and Tobacco Processing | 811 | Food Processing Related Machine Operators | 0.008
| 83   | Manufacture of Other Special Purpose Machinery, n.e.c. | 85441 | Industry Machinery Assemblers | 0.113
| 84   | Manufacture of Passenger Motor Vehicles | 85410 | Automobile Assemblers | 0.023
| 85   | Manufacture of Parts and Accessories for Motor Vehicles and Engines | 74130 | Forge Hammersmiths and Forging Press Workers | 0.001
| 86   | Manufacture of Parts and Accessories for Motor Engines | 85421 | Automobile Engine Assemblers | 0.07
| 87   | Manufacture of Other Parts and Accessories for Motor Vehicles n.e.c. | 75105 | Automobile Paint Mechanics | 1.05
| 88   | Manufacture of Other Parts and Accessories for Motor Vehicles n.e.c. | 85429 | Automobile Parts Assemblers n.e.c. | 0.18
| 89   | Manufacture of Other Parts and Accessories for Motor Vehicles n.e.c. | 85429 | Automobile Parts Assemblers n.e.c. | 0.42
| 90   | Building of steel ships | 75220 | Ship Mechanics | 0.13
| 91   | Manufacture of Sections for Ships | 85432 | Ship Assemblers | 1.23

(continued on next page)
| IOC numbers | Industry (KSIC, 10th) | Occupation (KSOC, 7th) | Exposure or sampling description | Concentration (f/cc) | References | The Netherlands (NL), Germany (DE) data |
|-------------|-----------------------|------------------------|----------------------------------|----------------------|------------|---------------------------------------|
| 92          | 31322 Manufacture of Aircraft Parts and Accessories | 85433 Aircraft Assemblers | 0.010 | SNU DB | 313-Manufacture of Aircraft, Spacecraft and its Parts and 7521-Aircraft Mechanics: 0.5–1 (1945–1979), 0–0.5 (1980–1984) (NL) |
| 93          | 3320 Manufacture of Musical Instruments | 73031 Musical Instrument Makers and Repairers | 0.019 | 0.022 | Lee, 2013 [40] |
| 94          | 33999 Other Manufacturing n.e.c. | 83124 Chemical Material Distiller and Reactor Operators | Melting and molding | 0.836 | Choi, 2006 [32] |
| 95          | 3511 Electric Power Generation | 8610 Power Generation and Distribution Equipment Operators | Maintenance workers in power plants | 0.004 | KOSHA DB | Power Plant Machinery Manufacturing and Thermal Power Plant Operators: 1–2 (1945–1979), 0.5–1 (1980–1989), 0–0.5 (1990–1994) (NL) 3.33, 3.55, 8.88, 1.11 (1956–1974) (DE) Maintenance and asbestos insulation and friction materials/maintenance (heating) plants and machinery/installation and repair of boilers and turbines, maintenance (heating) plants and machinery |
| 96          | 3511 Electric Power Generation | 23519 Machine Engineers and Researchers n.e.c. | 0.004 | Choi, 2006 [32] |
| 97          | 36010 Collection, Purification and Distribution of Water to Household | 8810 Water Treatment Plant Operators | 0.066 | Choi, 2006 [32] | 36-Water Supply and 792-Plumber: 1–2 (1945–1979), 0.5–1 (1980–1984), 0–0.5 (1990–1994) (NL) |
| 98          | 38120 Hazardous Waste Collection | 8820 Recycling Machine and Incinerator Operators | Waste treatment | 0.003 | Choi, 2006 [32] | 0–0.5 (1945–1994) (NL) |
| 99          | 38120 Hazardous Waste Collection | 91001 Construction Laborers | Sampling after dismantling asbestos | 0.005 | KOSHA DB | 742-Cleaning and Pest Control Services of Building and Industrial Facilities) and 941-Cleaners and Sanitation Workers: Asbestos water way cleaning 0–0.5 (1945–1994) (NL) |
| 100         | 382 Waste Treatment Services | 8820 Recycling Machine and Incinerator Operators | 0.016 | KOSHA DB |
| 101         | 38220 Disposal of Hazardous Waste | 88209 Recycling Machine and Incinerator Operator n.e.c. | Crushing waste-containing asbestos | 0.013 | KOSHA DB |
| Code  | Work Description                                                                 | Industry Code | Exposure Level | Source |
|-------|----------------------------------------------------------------------------------|----------------|----------------|--------|
| 102   | Installation of Environmental Hygiene Treatment Appliances                         | 88209          | 0.002          | KOSHA DB |
| 103   | Apartment Building Construction                                                    | 772            | 0.039          | SNU DB  |
| 104   | Other Civil Engineering Construction                                              | 23123          | 0.004          | Choi, 2006 [32] |
| 105   | Wrecking and Demolition of Buildings and Other Structures                          | 78293          | 0.042          | Choi, 2006 [32] |
| 106   | Excavating and earthmoving                                                         | 78499          | 0.001          | Choi, 2006 [32] |
| 107   | Steel Reinforcing and Reinforced Concrete Works                                   | 7822           | 0.001          | Choi, 2006 [32] |
| 108   | Pavement Works                                                                    | 7836           | 0.001          | Choi, 2006 [32] |
| 109   | Scaffolding and Frame Works                                                        | 78291          | 0.021          | Choi, 2006 [32] |
| 110   | Sale of Motor Vehicle New Parts and Accessories                                   | 52129          | 1.42           | Paik, 1989 [23] |

(continued on next page)
| IOC numbers | Industry (KSIC, 10th) | Occupation (KSOC, 7th) | Exposure or sampling description | Concentration (f/cc) | References | The Netherlands (NL), Germany (DE) data |
|-------------|----------------------|------------------------|---------------------------------|----------------------|------------|---------------------------------------|
| 111         | 471                  | Retail Sale in Non-Specialized Stores | 5211 Owners and Supervisors of Small Stores | 0.0002 0.003 | Kim, 2002 [43] | 466(Wholesale of Construction Materials, Hardware and Heating and Air Conditioning Equipment); and Construction Materials Salesperson: 2 –5(1945 –1969), 1–2(1970 –1979), 0–0.5(1980 –1994) (NL) |
| 112         | 47119                | Retail Sale in Other Non-Specialized Large Stores | 5211 Owners and Supervisors of Small Stores | 0.0053 | Lee, 2010 [36] |
| 113         | 501                  | Sea and Coastal Water Transport | 8760 Ship Workers and Related Workers | | NL | 501(Sea and Coastal Water Transport) and 8760(Ship Workers and Related Workers): 0.5–1(1945 –1974), 0–0.5(1975 –1984) (NL) 501(Sea and Coastal Water Transport) and 86104(Power Generation Turbine Operators): Turbine adjusters, asbestos pipes and pump insulation exposed in ship engine room 2–5(1945 –1974), 1–2(1975 –1979), 0.5–1(1980 –1994), 0–0.5(1990 –1994) (NL) |
| 114         | 50122                | Coastal freight water transport | 92101 Freight Loading and Lifting Laborers | | DE/NL | 50203(Harbour Passenger Transport) and 92101(Freight Loading and Lifting Laborers): 13.87(1965–1967), 26.61(1973–1976), 8.4(1977–1983) (DE) 5294(Cargo Handling) and 92101(Freight Loading and Lifting Laborers): 2–5(1945 –1969), 1–2(1970 –1979), 0–0.5(1980 –1994) (NL) |
| 115         | 52911                | Supporting, Railway Transport Activities | 31262 Railway Transport Clerks | Sampling in the station office 0.008 0.003 | Byeon, 2003 [30] Lee, 2013 [40] |
| 116         | 79211 (52911)        | Supporting, Railway Transport Activities | 7523 Locomotive and Electric Train Mechanics | Maintenance of locomotive and electric trains 0.002 | KOSHA DB | 491(Inter urban Rail Transportation) and 75319(Industrial Machinery Fitters and Mechanics n.e.c.); 0–0.5(1945–1984) (NL) |
| 117         | 52911                | Supporting, Railway Transport Activities | 75232 Railroad train mechanics | | SNU DB | 0–0.5 (1945–1984) (NL) |
| 118         | 52915                | Operation of Vehicle Parking Facilities | 52132 Passenger Ticket Salespersons | | Lee, 2010 [36] | |
| 119         | 59141                | Motion Picture Exhibition | 28399 Drama, Film and Video Related Workers n.e.c. | | Choi, 2011 [37] | |
| Code | Industry Code | Industry Description                                               | Occupation Code | Occupation Description                                      | Sampling Weight | Source 1 | Source 2 | Source 3 |
|------|---------------|-------------------------------------------------------------------|----------------|------------------------------------------------------------|----------------|----------|----------|----------|
| 120  | 6022          | Broadcasting via Cable, Satellite and Other Broadcasting           | 2250           | Telecommunication and Broadcast Transmissions Equipment Technicians | 0.005          | SNU DB   |          |          |
| 121  | 68211         | Residential Property Management                                    | 85201          | Cooler and Heater Related Machine Operators                | 0.002          | Choi, 2017 [10] |          |          |
| 122  | 95119         | Other Maintenance and Repair Services of General Machinery         | 75351          | Building Boiler Fitters and Mechanics                       | 0.006          | Shim, 2008 [33] |          |          |
| 123  | 70129         | Research and Experimental Development On Other Engineering         | 13114          | Engineering Research Managers                               | 0.112          | KOSHA DB |          |          |
| 124  | 72122         | Environmental Consulting and Related Engineering Services          | 15301          | Environmental Service Related Managers                     | 0.001          | Choi, 2006 [32] |          |          |
| 125  | 74100         | Business Facilities Support Management Services                    | 12090          | Public and Business Administration Managers                 | 0.0015         | Choi, 2006 [32] |          |          |
| 126  | 75290         | Other Tourist Assistance and Reservation Services                  | 52132          | Passenger Ticket Salespersons                               | 0.01           | Lee, 2004 [31] |          |          |
| 127  | 84213         | Regulation of Activities of Environment Affairs                   | 21125          | Astronomy and Space Science Researchers                    | 0.4705         | Choi, 2006 [32] |          |          |
| 128  | 85            | Education                                                          | 252            | School Teachers                                            | 0.00036 0.003 0.004 | Park, 2009 [34] | Park, 2010 [35] |          |
| 129  | 85501         | General Subject Educational Institute                               | 25419          | Liberal Arts and Language Instructors n.e.c.                | 0.007          | Choi, 2011 [37] |          |          |
| 130  | 8610          | Hospital Activities General Hospitals                               | 24302 24       | General Nurses Health, Social Welfare and Religion Related Occupations | 0.00049(2010): 0.002 | Choi, 2017 [10] | Lee, 2004 [31] | 86103(Dental Hospitals) and 24530(Dental Hygienist): 0 – 0.5(1955 – 1984) (NL) |
| 131  | 87210         | Child Day Care Services                                            | 24720          | Child Care Teachers                                         | 0.007 (2010): 0.001 | Lee, 2010 [36] | Park, 2012 [39] |          |
| 132  | 90211         | Library and Archives Activities                                     | 28221          | Librarians                                                 | 0.002          | Park, 2012 [39] |          |          |
| OGI33 | 90221        | Museum Operation                                                    | 28211          | Curators                                                   | 0.001          | Park, 2012 [39] |          |          |
| OGI34 | 91131        | Other Complex Sports Facility Operation                             | 28691          | Sports Instructors and Trainers                             | 0.006          | Choi, 2011 [37] |          |          |

(continued on next page)
| IOC numbers | Industry (KSIC, 10th) | Occupation (KSOC, 7th) | Exposure or sampling description | Concentration (f/cc) | References | The Netherlands (NL), Germany (DE) data |
|-------------|-----------------------|------------------------|---------------------------------|----------------------|------------|----------------------------------------|
| 135         | 95119 (50130) Other Maintenance and Repair Services of General Machinery | 75220 Ship Mechanics | Repair of ships | 0.23 | 0.006 | 0.138 | Paik, 1989 [23] SNUDB (2000): 1.423 Yoon, 2004 [44] |
|             |                       |                        |                                 |                      |            | 311(Building of Ships and Boats) and 7522(Ship Mechanics): 1–2(1945–1974), 0–0.5(1975–1989) (NL) 501(Sea and Coastal Water Transport) and 8760(Ship deck crew and related personnel): 0.5–1(1945–1974), 0–0.5(1975–1984) (NL) |
| 136         | 95119 (50130) Other Maintenance and Repair Services of General Machinery | 79222 Ship Plumbers | | 0.488 | | | Shim, 2008 [33] 311(Building of Ships and Boats) and 792(Plumber): 1–2(1945–1979), 0.5–1(1980–1984), 0–0.5(1985–1994) (NL) |
| 137         | 95119 Other Maintenance and Repair Services of General Machinery | 75220 Ship Mechanics | Repair of auto-vehicle brake lining and handling talc-containing asbestos | 0.062 | | | Shim, 2008 [33] |
| 138         | 95211 General Repair Services of Motor Vehicles | 75105 Automobile Paint Mechanics | | 0.88 | | | KOSHA DB |
| 139         | 95212 Repair Services of Motor Vehicles Specializing in Parts | 7510 Automobile Mechanics | | 0.93 | 1.05 | 0.08 | Paik, 1989 [23] Paik, 1991 [24] 952(Maintenance and Repair Services of Motor Vehicles and Motorcycles) and 75201(Motorcycle Repairers): 0–0.5(1945–1989) (NL) |
| 140         | 96121 Saunas | 42234 Bathing Attendants | | 0.007 (2010): 0.002 | Lee, 2010 [36] Park, 2012 [39] 9691(Washing and Dry Cleaning Services) and 8230(Laundry Related Machine Operators): Laundry iron and table made of asbestos fibers 0–0.5(1945–1989) (NL) |
| 141         | 96991 Wedding Chapel Services | 42320 Wedding Ceremony Workers | | 0.004 | | | Choi, 2011 [37] |

DB, database; IOC, Industrial and Occupational Combination; KOSHA, Korea Occupational Safety and Health Agency; KSIC, Korea Standard Industry Code; KSOC, Korean Standard Classification of Occupations; JEM, job-exposure matrix; SNU, Seoul National University; n.e.c, not elsewhere classified.

DBs were referred from Choi, 2017 [10].
industries and occupations. As it includes data of longer periods, more diverse industries, and occupations, it reflects the exposure estimate of asbestos in Korea more accurately.

4.1. Trends of asbestos consumption and exposure levels in Korea

The occupation groups with high asbestos exposure levels include knitting and weaving machine operators, automobile mechanics or assemblers, ship mechanics or assemblers, mineral ore and stone products processing mechanics, and metal casting machine operators or mold makers. This result is consistent with the national industrialized characteristics of Korea. In Korea, the asbestos textile weaving and brake lining production began to increase in the 1970s. With the acceleration of industrialization since the 1980s, asbestos imports increased, and asbestos use peaked in the 1990s [15]. In asbestos textile factories, the use of asbestos increased when the operations of J Chemical, Asia’s largest textile factory located in Busan, was transferred from Tatsuta of Nichias in Japan and Rex in Germany to Korea in 1971 and 1981, respectively [16]. In 2000s, the portion of occupational groups over 0.1f/cc exposure increased compared with that in 1990s. We found the reason that the data in the Korean Occupational Safety and Health Agency database were measured in talc-containing occupations; therefore, the highly exposed occupational groups were included making a biased trend in the proportion.

4.2. Cause of the time lag of periods with high exposure levels between Europe and Korea

As mentioned before, different sets of data cover asbestos exposure from the 1980s to the 2000s in Korea, 1945 to 1994 in the Netherlands, and the 1960s to the 2000s in Germany. While asbestos exposure levels peaked in the 1990s in Korea, most of the data from the Netherlands and Germany showed peak exposure levels from the 1950s to the 1970s. This finding could be due to the difference in asbestos usage patterns between Europe and Asia. One study estimated the proportion of asbestos use in Asia to be 14% in 1920–1970, 33% in 1971–2000, and 64% in 2000–2007, and these periods are later than those in Europe [17]. In a comparative analysis of asbestos use and exposure data for Germany and Korea, the asbestos exposure level in Korea in 1981 was comparable with that of Germany in 1974 [16,18]. Regarding categories of exposure levels, the highest level in Korea was classified as E1 (≥1 fibers/cm³); however, in the Netherlands, the highest exposure level was “F” (>10 fibers/cm³) and the lowest was “A” (0–0.5 fibers/cm³), which is higher than the highest level (E1) in Korea. Therefore, a quantitative comparison of exposure levels between Korea and the Netherlands is less meaningful; however, it can be used to identify trends associated with increasing or decreasing asbestos exposure levels.

4.3. Comparison with other JEMs (Finland, Australia, etc.)

There have also been trials to construct a systematic JEM for occupational asbestos exposure in other countries. Finnish National Job-Exposure Matrix, one of the most widely used JEMs, was constructed in the 1990s and contains 74 chemical, physical, biological, ergonomic, and socio-psychological factors, covering 311 occupational categories for the period 1945–1997. In Australia, an asbestos JEM was used for assessing occupational asbestos exposure and contains 537 combinations from 224 occupational categories and 60 industrialized categories and 4 time periods (1943–1966, 1967–1986, 1987–2003, and ≥2004) [19], which is called SYN-JEM, and the quantitative SYN-JEM for five carcinogens including asbestos was developed by modeling of personal measurements in previous JEM data, for the periods between 1971 and 2009 [20]. We could have used the asbestos JEM of Australia for this study as they have a large number of combinations; however, we could not access their raw data. However, compared with these foreign JEMs, the reconstructed asbestos JEM in this study estimated the exposure levels for 141 combinations by period and combined the Netherlands’ and Germany’s data as references for estimating asbestos exposure. As asbestos production and usage periods in Korea are different from those in Europe, we were not able to perform a direct comparison. Nevertheless, the reconstructed Korean asbestos JEM is a large-scale JEM that can represent asbestos exposure in Korea and other Asian countries.

4.4. Advantages and limitations

The reconstructed Korean asbestos JEM expands the previous 112 combinations to 141 combinations. The strength of this study is that we can estimate asbestos exposure during periods that are not covered by Korean data by referring to the Netherlands’ and Germany’s data. However, caution is required when interpreting estimates with a small data sample size, and it should be noted that asbestos exposure in Korea is different from those in countries of other continents. The narrow period of overlap between the Korean data and the Netherlands’ or Germany’s data is also a major cause of inaccurate estimates.

4.5. Further study

Analyzing the asbestos exposure using the reconstructed Korean JEM showed the highest exposure level in most occupations in the 1980s, which gradually decreased until the 2010s; however, some occupations emerged as highly exposed groups in the 2000s. Further research on these new asbestos occupational groups and a close follow-up study are necessary. A diverse approach for data on past exposure levels before the 1980s is also needed.

5. Conclusions

The reconstructed Korean asbestos JEM has expanded the type and duration of the occupational groups to 141 combinations for periods between the 1980s and 2010s. This JEM can serve as an important reference tool for evaluating asbestos exposure in Korean workers and providing basic data for compensation and prevention policies for asbestos-exposed workers.

Author contribution

Jung S wrote the manuscript. Kang DM designed the study and helped in the drafting and critical revision of the manuscript. Choi S performed data collection and extraction. Kim YJ analyzed the data.

Conflicts of interest

All authors have no conflicts of interest to declare.

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Appendix 1. summary of final references selected in the JEM
| References | Study ID | Title | Amount of measurement | Working environment |
|------------|----------|-------|-----------------------|---------------------|
| [21] | Moon YH, 1979 | Epidemiological survey of asbestosis in asbestos miners and the inhabitants | 0.092316–0.38465 fiber/cm³ inside the mine, 2.267–5.966 fiber/cm³ at the annex factory, and at outside of the office it was 3.882 fiber/cm³ | Forty-one workers in asbestos mine and the annex factory in Korea |
| [22] | National Institute of Labor Science Ministry of Labor, 1984 | Survey report of working environment at several factories | Asbestos textile industry: - Mixing: 9.71 fiber/cc (0.62–24.80 fiber/cc) - Weaving: 8.77 fiber/cc (1.17–30.73 fiber/cc) - Carding: 3.46 fiber/cc (0.65–7.85 fiber/cc) Slate manufacturing: 0.4 fiber/cc (0.12–0.57 fiber/cc) Brake-lining manufacturing: 1.7 fiber/cc (1.14–1.85 fiber/cc) | Measured in six asbestos textile plants, one slate manufacturing plant, and one automobile product manufacturing plants between 1984.4.21 and 1984.9.20 |
| [23] | Paik NW, 1989 | Workers Exposure to Asbestos in Korean Asbestos Industries | Slate manufacturing industry: - Mixing: 0.49–0.56 fiber/cc - Processing: 0.35–1.23 fiber/cc - Molding(Wet): 0.13 fiber/cc Asbestos textile industry: - Fiberizing, mixing: 0.23–3.67 fiber/cc - Carding: 0.08–9.44 fiber/cc - Spinning: 0.30–9.73 fiber/cc - Twisting: 0.08–14.90 fiber/cc - Weaving: 1.34–5.60 fiber/cc Shipbuilding industry: - Without removing asbestos materials: 0.01–0.12 fiber/cc - With removing asbestos materials: 0.09–2.45 fiber/cc - Automobile maintenance industry: 0.03–4.26 fiber/cc - Automobile product manufacturing: 0.16–5.56 fiber/cc - Asbestos related industry: 0.01–4.30 fiber/cc | Workers of 11 plants which is asbestos slate manufacturing, asbestos textile, automobile maintenance, automobile product manufacturing, and asbestos-related industries |
| [24] | Paik NW, 1991 | Characterization of Worker Exposure to Airborne Asbestos in Asbestos Industry | Large variation of asbestos level was found by plants: 0.5 to over 10 fiber/cc | Eleven plants including asbestos textile, brake-lining manufacturing, slate manufacturing, and automobile maintenance shop |
| [25] | Oh SM, 1993 | A study on worker exposure level and variation to asbestos in some asbestos industries | Geometric means of airborne asbestos concentration - Textile industry: 1.42 fiber/cc (0.07–6.10 fiber/cc) - Brake lining manufacturing industry: 0.19 fiber/cc (<0.01–2.67 fiber/cc) - Slate manufacturing industry: 0.08 fiber/cc (0.025–0.67 fiber/cc) | Seventeen plants including asbestos textile, brake-lining manufacturing, slate manufacturing, and automobile maintenance shop |
| [26] | Jung JY, 1994 | A case of asbestosis, pleural effusion and lung cancer caused by long-term occupational asbestos exposure | Asbestos concentration in workplace: 0.01–0.08 fiber/cc | A case of asbestosis and lung cancer of who were occupationally exposed in asbestos for 11 years. |
Park JI, 1995
A study of exposure among asbestos textile workers and estimation of their historical exposures
Among 56 samples
- Average concentration: 1.54f/cc (0.03 – 11.58f/cc)
By processing
- Weaving: 4.29f/cc (2.61 – 11.58f/cc)
- Spinning: 2.22f/cc (0.41 – 8.93f/cc)
- Carding: 1.98f/cc (0.23 – 10.93f/cc)
- Twisting: 1.65f/cc (0.21 – 9.83f/cc)
- Mixing: 0.48f/cc (0.22 – 1.20f/cc)

Paik DM, 1995
Prevalence of asbestosis in Korean asbestos industry
Asbestos textile: 0.2 – 1.3f/cc
Brake-lining: 0.7 – 1.0f/cc
Ship repairing: 6.3 – 7.8f/cc

Choi JK, 1998
The production, the use, the number of workers, and exposure level of asbestos in Korea
The record of air-borne asbestos
- Textile industry: 6.7f/cc (1984), 1.2f/cc (1993)
- Construction materials and asbestos textile: 1.7f/cc (1984), 0.55f/cc (1996)

Byeon SH, 2003
A study on asbestos fibers and the notice of inhabitant in the Bu-Pyung station
Six samples (43%) exceeded Environmental Production Agency criteria of 0.01f/cc

Lee YG, 2010
Concentration and Physical Chemical Properties of Fiber particles in Indoor and Outdoor Air
Geometric mean:
- Elementary school: 0.00108f/cc
- Middle school: 0.00105f/cc
- High school: 0.00107f/cc

Activity-based sampling: 216 samples in three mines

Lee SH, 2010
Concentration and Physical Chemical Properties of Fiber phase particles in Indoor and Outdoor Air
Geometric mean:
- Elementary school: 0.00108f/cc
- Middle school: 0.00105f/cc
- High school: 0.00107f/cc

735 sites in school, seven sites in hospital, and four sites in kindergarten constructed before 2005

Lee SH, 2010
Concentration of asbestos fiber in Indoor Air according to the School's construction year
Geometric mean: < 0.01f/cc
By constructed year:
- Before 1969: 0.00028f/cc
- 1970s: 0.0040f/cc
- 1980s: 0.0035f/cc
- 1990s: 0.0030f/cc

108 sites of elementary, middle, and high school

Lee GY, 2013
Airborne Asbestos Fiber Concentration in Korean Asbestos-Related Industry from 1994 to 2006
Asbestos textile: 2.14 f/cc (0.02 – 15.6 f/cc)
Building materials: 0.26 f/cc (0.01 – 1.01 f/cc)
Brake-lining manufacturing: 0.15 f/cc (0.01 – 0.93 f/cc)
Commutator producing: 0.14 f/cc (0.03 – 1.36 f/cc)
Airborne asbestos fiber concentrations in asbestos textile, brake-lining, commutator, and building materials manufacturing industries, and some other asbestos-related industries in Korea

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