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Original Article

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.

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, asbestosis, and pleural disease (pleural plaque and pleural thickening) [1]. Asbestosis 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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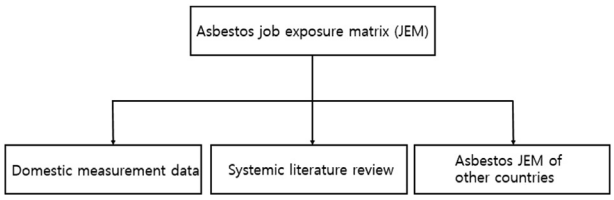

Fig. 1. Composition of data for new construction of the asbestos JEM.

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

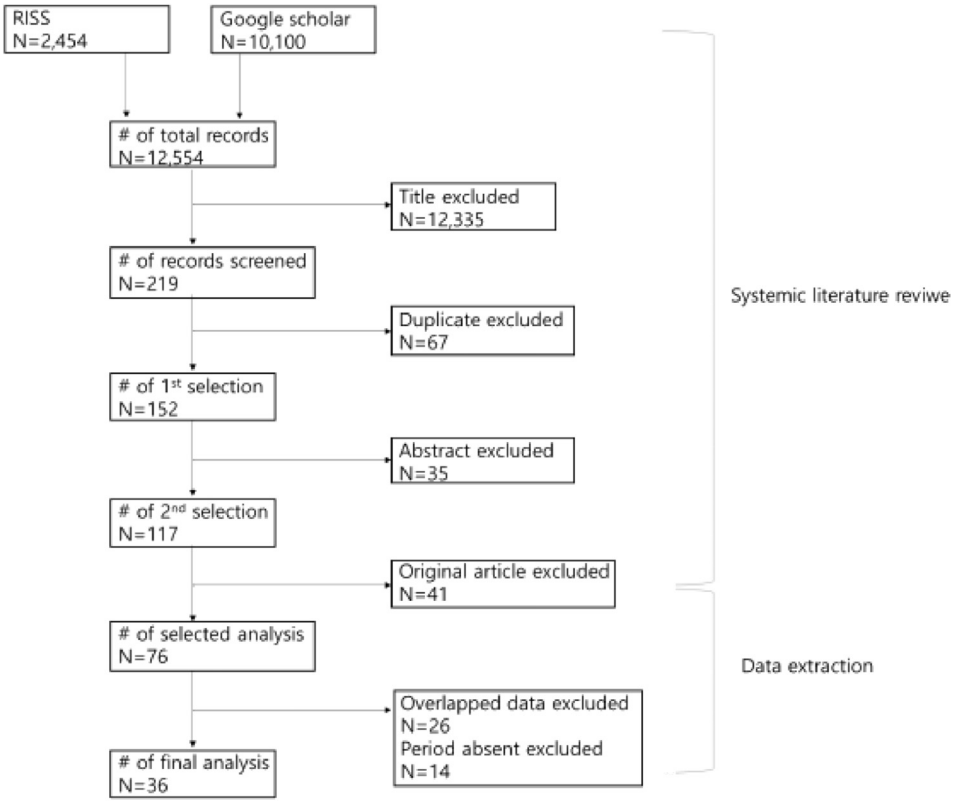

Fig. 2. Flow of the systemic literature review and data extraction.

- 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 Occupation 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 Korean Standard Classification of Occupations (KSOC). The exposure level was divided into seven codes: “0,” no exposure; “a,” 0–0.5 fibers/cm^3; “b,” 0.5–1 fibers/cm^3; “c,” 1–2 fibers/cm^3; “d,” 2–5 fibers/cm^3; “e,” 5–10 fibers/cm^3; and “f,” ≥10 fibers/cm^3.

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
The number of exposure groups of occupations by year *N* (%)

Exposure groups	1980	1990	2000
E1	6(42.9)	5(9.3)	6(5.1)
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/cm^3, E2: 0.1–1 fibers/cm^3, E3: 0.01–0.1 fibers/cm^3, and E4: <0.01 fibers/cm^3.

3. Results

For Korean data, we designated the exposure level into four categories: E1, ≥1 fibers/cm^3; E2, ≥0.1 fibers/cm^3; E3, 0.01–0.1 fibers/cm^3; and E4, <0.01 fibers/cm^3. 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, 7.48 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)		Occupation (KSOC, 7th)		Exposure or sampling description	Concentration (f/cc)			References	The Netherlands (NL), Germany (DE) data
	Code	Name	Code	Name		1980s	1990s	2000s		
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]	07290(Mining of Other Non-metal Ores n.e.c.) and 792(Plumber): 1–2 (1945–1974) (NL) (nonasbestos mines: working with asbestos insulation, using asbestos mats and mattresses/installation and repair and maintenance of boilers and turbines [heating])
3	07290	Mining of Other Non-metal Ores n.e.c.	78412	Quarrymen				0.006	Yoon, 2011 [38]	07290(Mining of Other Non-metal Ores n.e.c.) and 784(Mining and Civil Engineering Related Technical Workers): 0–0.5 (1945–1974) (NL) non asbestos mine: exposed by lifts Railway vehicles (such as brake linings) in mines
4	10301	Processing and Preserving of Fruit and Vegetables, Pickled Food	71052	Side Dish Makers				0.013	Choi, 2006 [32]	1072(Manufacture of Sugar) and 2321(Chemical Engineers and Researchers): sugar production, asbestos insulation, indirect exposure to ropes and friction materials 1–2 (1945–1979), 0–0.5 (1980–1994) (NL)
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	17(Manufacture of Pulp, Paper and Paper Products) and 8913(Pulp and Paper Machine Operators): 0–0.5 (1945–1979) (NL)

(*continued on next page*)

Table 2 (*continued*)

IOC numbers	Industry (KSIC, 10th)		Occupation (KSOC, 7th)		Exposure or sampling description	Concentration (f/cc)			References	The Netherlands (NL), Germany (DE) data
	Code	Name	Code	Name		1980s	1990s	2000s		
10	17129	Manufacture of Other Paper and Paperboard	8914	Paper products production machine operators	Handling talc-containing asbestos			1.61	KOSHA DB	
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	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	Constructi0on 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 n.e.c.	Handling talc-containing asbestos			0.961	KOSHA DB
31	22199	Manufacture of Other Rubber Products n.e.c.	83222	Rubber Products Production Machine Operators			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

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Table 2 (*continued*)

IOC numbers	Industry (KSIC, 10th)		Occupation (KSOC, 7th)		Exposure or sampling description	Concentration (f/cc)			References	The Netherlands (NL), Germany (DE) data
	Code	Name	Code	Name		1980s	1990s	2000s		
35	22299	Manufacture of Other Plastic Products n.e.c.	83239	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	83239	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.	84319	Glass and Glass Products Machine Operators n.e.c.	Working around mercury filling and air vent machines			0.007	KOSHA DB	231(Manufacture of Plastic Sacks, Bags and Similar Products) and 8431(Glass Fabricating and Processing Machine Operators): 0.5−1 (1945−1979), 0−0.5 (1980−1989) (NL)
38	23211	Manufacture of Pottery and Ceramic Household or Ornamental Ware	84321	Pottery and Porcelain Products Production Machine Operators				0.006	KOSHA DB	
	23229	Manufacture of Other Refractory Ceramic Products	84319	Glass and Glass Products Machine Operators n.e.c.			0.064		Choi, 2006 [32]	
39	23229	Manufacture of Other Refractory Ceramic Products	84322	Brick and tile molding machine operators			0.0642		SNU DB	
	23229	Manufacture of Other Refractory Ceramic Products	84399	Nonmetal Products Related Production Machine Operators n.e.c.			0.069	0.069	SNU DB	
40	23239	Manufacture of Other Structural Non-refractory Clay and Ceramic Products	8432	Clay Products Production Machine Operators				0.004	Choi, 2006 [32]	
41	23324	Manufacture of Cellulose Fiber Cement Products	84331	Cement and Lime Production Related Machine Operators	Extruding molding of cement			0.013	KOSHA DB	
42	23325	Manufacture of Concrete Roofing Tiles, Bricks and Blocks	84322	Brick and Tile Production Machine Operators			0.059		Choi, 2006 [32]	

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)
49	23994	Manufacture of Asbestos, Mineral Wools and Other Similar Products	83121	Chemical Material Grinding and Mixing Machine Operators			0.06		Jung, 1994 [26]	

(*continued on next page*)

Table 2 (*continued*)

IOC numbers	Industry (KSIC, 10th)		Occupation (KSOC, 7th)		Exposure or sampling description	Concentration (f/cc)			References	The Netherlands (NL), Germany (DE) data
	Code	Name	Code	Name		1980s	1990s	2000s		
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	23994(Manufacture of Asbestos, Mineral Wools and Other Similar Products) and 84331(Cement and Lime Production Related Machine Operators): 5–10 (1945–1954), 2–5 (1955–1964), 0.5–1 (1965–1974), 0–0.5 (1975–1994) (NL)
53	23999	Manufacture of Other Unclassified Non-metallic 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	

58	25911 (25999)	Manufacture of Powder Metallurgic Products	84159	Metal Processing Machine Operators n.e.c.	Melting of metal powders		0.003	KOSHA DB	Lock manufacturing and 7534(Refrigerating System, Freezer, and Ventilating System Fitters and Mechanics): 1.62 (1955–1961), 0.6 (1955–1961) (DE) 20121(Manufacture of Industrial Gases) and 899(Other Machine Operators): 0–0.5(1970–1984) (NL)
59	25912 (24)	Forging of Metal/ Manufacture of Basic Metal Products	74130	Forge Hammer smiths and Forging Press Workers			0.008	KOSHA DB	25(Manufacture of Fabricated Metal Products, Except Machinery and Furniture) and 741(Die and Mold Makers, Metal Casting Workers and Forge Hammer smiths): 0–0.5 (1945–1984) (NL) 25(Manufacture of Fabricated Metal Products, Except Machinery and Furniture) and blacksmith: 2–5 (1945–1974), 1–2 (1975–1984), 0.5–1 (1985–1994) (NL)
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	Operation of furnace heat treatment		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	Asbestos paint industry and paint mixer: 2–5 (1945–1974), 0.5–1 (1975–1979), 0–0.5 (1980–1994) (NL)
63	25934	Manufacture of Saws, Saw Blades and Interchangeable Tools	74110	Die and Mold Makers		0.009	0.009	SNU DB	2592(Treatment and Coating of Metals) and 7411(Mold maker): 0–0.5 (1945–1984) (NL)
64	26299	Manufacture of Other Electronic Valves, Tubes and Electronic Components n.e.c.	86321	Electronic Parts Production Equipment Operators		0.011	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	

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Table 2 (*continued*)

IOC numbers	Industry (KSIC, 10th)		Occupation (KSOC, 7th)		Exposure or sampling description	Concentration (f/cc)			References	The Netherlands (NL), Germany (DE) data
	Code	Name	Code	Name		1980s	1990s	2000s		
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	2811 (Manufacture of Electric Motors, Generators and Transformers) and thermal power plant operators: 3.33, 3.55, 8.88, 1.11 (1956−1974) (DE)
72	28302	Manufacture of Other Insulated Wire and Cable	86402	Audio-Visual Equipment Assemblers				0.358	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)
73	28303	Manufacture of Insulated Codes Sets and Other Conductors for Electricity	86401	Electrical Equipment Assemblers	Extrusion of electric cables			0.125	KOSHA DB	4231(Electrical Works) and 862 (Electrical and Electronic Equipment Operators): exposed in boiler, furnace, turbine, pump maintenance repairs, and electric installation 1−2 (1945−1974), 0−0.5 (1980−1994) (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	89904	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	

79	29169	Manufacture of Other Work trucks, Lifting and Handling Equipment	8544	General Machinery Assemblers			0.009	0.009	SNU DB	
80	29210	Manufacture of Agricultural and Forestry Machinery	83239	Plastic Products Production Machine Operators n.e.c.	Manufacturing of agricultural machines			0.003	KOSHA DB	Fertilizer industry and 862(Electrical and Electronic Equipment Operators): 1–2 (1945–1979), 0–0.5 (1980–1994) (NL)
81	29210	Manufacture of Agricultural and Forestry Machinery	85442	Agricultural Machinery Assemblers			0.046		SNU DB	Farmer: Farm machinery maintenance Exposure to asbestos cement on roof and wall materials: 0–0.5 (1955–1994) (NL)
82	29250	Manufacture of Machinery for Food, Beverage and Tobacco Processing	811	Food Processing Related Machine Operators			0.008		SNU DB	
83	29299	Manufacture of Other Special Purpose Machinery, n.e.c.	85441	Industry Machinery Assemblers				0.113	KOSHA DB	
84	30121	Manufacture of Passenger Motor Vehicles	85410	Automobile Assemblers			0.023	0.023	SNU DB	
85	303	Manufacture of Parts and Accessories for Motor Vehicles and Engines	74130	Forge Hammersmiths and Forging Press Workers				0.001	KOSHA DB	
86	30310	Manufacture of Parts and Accessories for Motor Engines	85421	Automobile Engine Assemblers	Cutting with press machines		0.07	0.002	SNU DB KOSHADB	
87	30399	Manufacture of Other Parts and Accessories for Motor Vehicles n. e. c.	75105	Automobile Paint Mechanics	Handling talc-containing asbestos			1.05	KOSHA DB	
88	303	Manufacture of Other Parts and Accessories for Motor Vehicles n. e. c.	85429	Automobile Parts Assemblers n.e.c.			0.18	0.18	SNU DB	
89	30399	Manufacture of Other Parts and Accessories for Motor Vehicles n. e. c.	85429	Automobile Parts Assemblers n.e.c.	Manufacturing of brake lining	0.42	0.42	0.033	KOSHA DB Paik, 1989 [24] Oh, 1993 [25] Choi, 1998 [29]	
90	31111	Building of steel ships	75220	Ship Mechanics	Shipbuilding		0.13	0.13	SNU DB	311(Building of Ships and Boats) and 7522(Ship Mechanics): 1–2 (1945–1974), 0–0.5 (1975–1989) (NL)
91	31114	Manufacture of Sections for Ships	85432	Ship Assemblers	Ship machine processing	1.23	0.057	0.035	Choi, 2017 [10] Paik, 1995 [28]	311(Building of Ships and Boats): Working in asbestos insulated pipelines/working spray processing places 1–2 (1945–1989), 0.5–1 (1990–1994) (NL)

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Table 2 (*continued*)

IOC numbers	Industry (KSIC, 10th)		Occupation (KSOC, 7th)		Exposure or sampling description	Concentration (f/cc)			References	The Netherlands (NL), Germany (DE) data
	Code	Name	Code	Name		1980s	1990s	2000s		
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	

102	41224	Installation of Environmental Hygiene Treatment Appliances	88209	Recycling Machine and Incinerator Operator n.e.c.				0.002	KOSHA DB	
103	41112	Apartment Building Construction	772	Broadcasting and Tele communications Equipment Related Fitters and Repairers			0.039	0.039	SNU DB	41(General Construction) and 7831(plasterer): 0–0.5 (1945–1994) (NL)
104	41229	Other Civil Engineering Construction	23123	Building Construction Engineers				0.004	Choi, 2006 [32]	7829(Roof repair and Other Civil Engineering Construction): 0.34, 0.03, 1.5,0.47, 0.28 (1966–1970), 1.38, 0.34, 2.75, 1.72, 1.03, 0.14 (1972–1985) (DE)
105	42110	Wrecking and Demolition of Buildings and Other Structures	78293	Building Demolition Workers			0.042	0.004	Choi, 2006 [32]	Asbestos removal/asbestos demolition/ship part dismantle/asbestos insulation (strip) elimination/ dismantle, >10 (1945–1979), 5–10 (1980–1989), 1–2 (1990–1994) (NL)
106	42121	Excavating and earthmoving	78499	Mining and Civil Engineering Related Workers n.e.c.				0.001	Choi, 2006 [32]	
107	42132	Steel Reinforcing and Reinforced Concrete Works	7822	Concrete Placers and Assemblers				0.001	Choi, 2006 [32]	Boiler-heater and bricklayer: 0.67(1972), 0.5(1984) (DE)
108	42134	Pavement Works	7836	Construction Painters				0.001	Choi, 2006 [32]	41221(Construction of Highways, Streets and Roads) and 87505(Road Paving and Roller Drivers): Asbestos-containing asphalt work 0 –0.5(1975–1984) (NL)
109	42137	Scaffolding and Frame Works	78291	Scaffolders				0.021	Choi, 2006 [32]	
110	4521	Sale of Motor Vehicle New Parts and Accessories	52129	Store Salespersons n.e.c.	Handling of auto-vehicle brake for selling	1.42			Paik, 1989 [23]	46692(Wholesale of Wallpaper and Floor Coverings) and 72199 (Textile and Leather Related Workers n.e.c.): Sales of retail textiles, flooring, asbestos paper, felt 0 –0.5(1970–1989) (NL)

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Table 2 (*continued*)

IOC numbers	Industry (KSIC, 10th)		Occupation (KSOC, 7th)		Exposure or sampling description	Concentration (f/cc)			References	The Netherlands (NL), Germany (DE) data
	Code	Name	Code	Name		1980s	1990s	2000s		
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(1980−1984), 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				0.037	SNU DB	0−0.5 (1945−1984) (NL)
118	52915	Operation of Vehicle Parking Facilities	52132	Passenger Ticket Salespersons				0.004 (2010‘: 0.001)	Lee, 2010 [36]	
119	59141	Motion Picture Exhibition	28399	Drama, Film and Video Related Workers n.e.c.				0.006	Choi, 2011 [37]	

120	6022	Broadcasting via Cable, Satellite and Other Broadcasting	2250	Tele communication and Broadcast Transmissions Equipment Technicians			0.005	0.005	SNU DB	8432 (Defence Activities) and 22501(Telecommunication and Broadcast Transmissions Equipment Technicians): 0.5−1(1945−1974), 0−0.5(1975−1984) (DE)
121	68211	Residential Property Management	85201	Cooler and Heater Related Machine Operators	Management of boiler rooms in apartments			0.002	Choi, 2017 [10]	42201(Heating, Air Conditioning and Plumbing Related Works) and 852(Cooler and Heater Related Machine Operators): 1−2(1945−1979), 0−0.5(1980−1994) (NL)
122	95119	Other Maintenance and Repair Services of General Machinery	75351	Building Boiler Fitters and Mechanics				0.006	Shim, 2008 [33]	351(Production, Collection and Distribution of Electricity) and 7535(Boiler Fitters and Mechanics): 2−5(1945−1974), 1−2(1975−1984), 0.5−1(1985−1994) (NL)
123	70129	Research and Experimental Development On Other Engineering	13114	Engineering Research Managers	Sampling in the laboratory			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 86101 86103	Hospital Activities General Hospitals	24302 24	General Nurses Health, Social Welfare and Religion Related Occupations	Sampling in dental hospital			0.0049(2010': 0.002)	Choi, 2017 [10] Lee, 2004 [31]	86103(Dental Hospitals) and 24530(Dental Hygienist): 0−0.5(1955−1984) (NL)
131	87210 85110	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]	
OG133	90221	Museum Operation	28211	Curators				0.001	Park, 2012 [39]	
OG134	91131	Other Complex Sports Facility Operation	28691	Sports Instructors and Trainers				0.006	Choi, 2011 [37]	

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Table 2 (*continued*)

IOC numbers	Industry (KSIC, 10th)		Occupation (KSOC, 7th)		Exposure or sampling description	Concentration (f/cc)			References	The Netherlands (NL), Germany (DE) data
	Code	Name	Code	Name		1980s	1990s	2000s		
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				0.062	Shim, 2008 [33]	
138	95211	General Repair Services of Motor Vehicles	75105	Automobile Paint Mechanics	Repair of auto-vehicle brake lining and handling talc-containing asbestos			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 75291(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 ($\geq$1 fibers/cm^3); however, in the Netherlands, the highest exposure level was “f” ($>$10 fibers/cm^3) and the lowest was “a” (0–0.5 fibers/cm^3), 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 $\geq$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.

Acknowledgments

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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: 9.71f/cc (0.62–24.80f/cc) - Weaving: 8.77f/cc (1.17–30.73f/cc) - Carding: 3.46f/cc (0.65–7.85f/cc) Slate manufacturing: 0.4f/cc (0.12–0.57f/cc) Brake-lining manufacturing: 1.7f/cc (1.14–1.85f/cc)	Measured in six asbestos textile plants, one slate manufacturing plants, 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: 0.49–0.56f/cc - Processing: 0.35–1.23f/cc - Molding(Wet): 0.13f/cc Asbestos textile industry: - Fiberizing, mixing: 0.23–3.67f/cc - Carding: 0.08–9.44f/cc - Spinning: 0.30–9.73f/cc - Twisting: 0.08–14.90f/cc - Weaving: 1.34–5.60f/cc Shipbuilding industry: - Without removing asbestos materials: 0.01–0.12f/cc - With removing asbestos materials: 0.09–2.45f/cc - Automobile maintenance industry: 0.03–4.26f/cc - Automobile product manufacturing: 0.16–5.56f/c - Asbestos related industry: 0.01–4.30f/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 f/ccs	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: 1.42f/cc (0.07–6.10f/cc) - Brake lining manufacturing industry: 0.19 f/cc (<0.01–2.67 f/cc) - Slate manufacturing industry: 0.08f/cc (0.025–0.67 f/cc)	15 plants of brake lining manufacturing industry, seven plants of textile industry, and two plants of slate manufacturing industry
[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/f/cc	A case of asbestosis and lung cancer of who were occupationally exposed in asbestos for 11 years.

[27]	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)	Asbestos exposure level among asbestos textile workers in six plants
[28]	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	139 workers from five asbestos industries: two asbestos textile, one brake-lining, and two ship repairing industry
[29]	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)	Literature review
[30]	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	Bu-pyung basement stores in Korea (sep 25 to Oct 26, 2001)
[31]	Lee YG, 2004	A Study on the Actual Condition of Indoor Air Quality in Multi-use Facilities	Underground station: 0.17f/cc	Underground station (B1 ticket gate, B2 platform)
[33]	Shim SH, 2008	A Study on Exposure to Asbestos a Shipbuilding Repair Business	Geometric mean: 0.004 f/cc - Plumbing repair: 0.0071 f/cc (0.001~0.57 f/cc) while - Boiler: 0.0015 f/cc (0.001~0.007 f/cc)	27 workers who had been exposed to asbestos in shipbuilding repair company
[34]	Park JH, 2009	The 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: 0.0036f/cc 1990s: 0.0030f/cc	108 sites of elementary, middle, and high school
[35]	Park JH, 2010	Characterizations of Airborne Fiber Particle Concentration in Public Facilities and Schools	0.0009±0.0009 counts/mL in public facilities 0.0012±0.0006 counts/mL in schools	Indoor air concentration of fiber particles in 30 public facilities and 245 schools by PCM
	Lee SH, 2010	Concentration and Physical Chemical Properties of Fiber phase Particles in Indoor and Outdoor Air	Geometric mean of - 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
[38]	Yoon YS, 2011	Comparison of asbestos exposure and risk assessment according to asbestos mine types in Korea	By scenario: - Motorcycle: 0.0702f/cc (SD 0.2640) - Cultivator: 0.0358f/cc (SD 0.1017) - Walk: 0.0730 (SD 2631) - Weed control: 0.0941 (SD 0.2901) - Digging: 0.1396 (SD 0.4633) - Field Sweep: 0.2009 (SD 0.3056)	Activity-based sampling: 216 samples in three mines
[39]	Park HE, 2012	Concentration Characteristics of Indoor and Outdoor Airborne Total Fiber Particles and Identification of Asbestos in Gyeong-Nam Provinces	School: 0.0011 ± 0.0007 f/cc Public facilities: 0.0015 ± 0.0007 f/cc	748 samples of 748 schools, and 76 samples of 38 public facilities
40	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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References	Study ID	Title	Amount of measurement	Working environment
[41]	Yoon IJ, 1993	Epidemiological Survey on the Environment and Health Status in Asbestos Factories	Average concentration of nine industries: 0.682 f/cc (0.19–2.08 f/cc) 0.208 f/cc (0.09–0.37 f/cc) 3.36 f/cc (2.40–7.15 f/cc) 0.415 f/cc (0.18–1.26 f/cc) 0.157 f/cc (0.06–0.50 f/cc) 0.375 f/cc (0.27–0.75 f/cc) 0.768 f/cc (0.65–1.15 f/cc) 1.48 f/cc (range 0.21–5.04 f/cc)	378 workers from nine asbestos industries using chrysotile
[42]	Lim HS, 1999	A Case of Lung Cancer Occurred among Asbestos Workers in a Steel Manufacturing Factory	0.0007–0.0101 f/cc	A case of 39-year-old worker who worked in a steel manufacturing factory for 17 years
[43]	Chung HJ, 2002	A Study on Asbestos Concentration of Underground Shops in Daejeon area	Summer: 0.0041 f/cc Spring: 0.0033 f/cc Winter: 0.0022 f/cc Fall: 0.0020 f/cc	In underground shops in Daejeon city

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