Article

Development of Nationwide Excess Lifetime Cancer Risk Evaluation Methods with Comprehensive Past Asbestos Exposure Reconstruction

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Abstract: Although exposure to asbestos via various routes has been acknowledged, comprehensive exposure and risk assessment methods have not been developed at the national level. We conducted a study to reconstruct comprehensive past asbestos exposure estimations and to suggest a method to calculate the Excess Lifetime Cancer Risk (ELCR) of Koreans. The past occupational exposure reconstruction was conducted by rebuilding the previous general population job-exposure matrix (JEM). The para-occupational and household exposure estimation was based on the pooled analysis of data from other countries as well as Korea. The neighborhood exposure from occupational sources by distance was estimated by the exponential decay model. As a result, 141 JEM exposure groups across four periods including ~79, the 80s, 90s, 2000s with a ratio of 2.0:1.0:0.5:0.05 were reconstructed. The para-occupational and household exposures were 11% and 1% of the JEM respectively. The environmental exposure source concentration from outside occupational exposure was 2.5% of the inside concentration. The ratio of the concentration of environmental exposure source (Ci) to distance d (Ca) was $\exp^{-kd}$ with a decay constant k of 6.834. The mean concentrations (f/cc) were 2.28 $\times 10^{-3}$ for outdoor, 4.65 $\times 10^{-5}$ for indoor, 1.95 $\times 10^{-2}$ for transportation activity, 4.44 $\times 10^{-2}$ for agricultural activity, and 4.68 $\times 10^{-2}$ for daily life activity in naturally occurring asbestos areas. Indoor and outdoor asbestos concentrations from living in a slate roof house were 1.73 $\times 10^{-6}$ and 2.70 $\times 10^{-5}$, respectively. For improved generalizability, validity, and applicability of the proposed method, further studies on each route with real assessments and experiments are required.

Keywords: asbestos; past; excess; lifetime; cancer; risk; occupational; environmental; exposure; Korea

1. Introduction

All forms of asbestos are well known to cause asbestos-related diseases (ARDs) including benign diseases such as asbestosis and pleural plaques (thickening), and malignant cancers such as malignant mesothelioma (MM), lung cancer (LC), laryngeal cancer, and ovarian cancer [1]. The exposure routes to asbestos via various sources including occupational, para-occupational, neighborhood, and household have been acknowledged since the 1960s [2–4]. The major sources of occupational asbestos exposure are asbestos mines, asbestos cement and textile factories, and workplaces handling asbestos products including shipyards and construction sites. Indirect occupational (para-
occupational) exposure could occur among workers who do not directly deal with asbestos. Asbestos emission from occupational sources could result in neighborhood exposure for people living close to the sources. Naturally occurring asbestos (NOA) and living in an area having an asbestos slate roof are contemporary asbestos exposure situations [5]. As occupational exposure can also cause household exposure to families from the asbestos-contaminated working clothes of exposed workers, occupational exposure assessment may be the starting point to estimate neighborhood and household exposures.

Because ARDs have long latency periods from at least 10 years to as long as 50 years [6], it is necessary to reconstruct previous exposure routes to establish their link with current ARDs. The job-exposure matrix (JEM) is one way to estimate past occupational exposure with limited information on the general working population [7]. Although the reconstruction of the Korean JEM extended to combinations of industrial and occupational groups [8], the missing information in each cell and period before 1979 needs to be filled to function as starting points for other exposure estimations. The neighborhood exposure estimation of the general population at the country level requires information regarding nationwide environmental exposure sources [9]. While the emission from inside to the outside of an exposure source could be checked by a simultaneous assessment of both sides, it is hard to find such a study. When the ambient air concentration of a neighborhood exposure source point is known, dispersion to the surrounding area could be estimated by a mathematical model such as the exponential decay by distance model or modeling using meteorological data [10,11]. Nationwide comprehensive asbestos exposure estimation needs tremendous effort including the collection of data and exposure reconstructions via various exposure routes.

Exposure assessment and estimation are used for epidemiological studies and compensation purposes. While the reference dose leading to benign ARDs has not been suggested so far, exposure estimations for increasing cancer risk could be useful. While the Helsinki criteria indicated a doubling of lung cancer risk, with a cumulative exposure dose of 25 fiber-years/cc [12], recent studies lowered the cumulative exposure dose for lung cancer risk [13]. As the Helsinki criteria mainly suggested a cut-off value, quantitative risk assessment methods such as Excess Lifetime Cancer Risk (ELCR) of asbestos proposed by the US Environmental Protection Agency (EPA) give more information to the public [14]. We conducted a study to reconstruct past asbestos exposure estimations from various exposure routes and to suggest a method for calculating the Korean ELCR.

2. Materials and Methods

2.1. Korean Asbestos JEM Reconstruction

Two methods were used to fill in the blanks of the recent Korean asbestos JEM containing 141 combinations (exposure groups) of industries and occupations over three decades (the 80s, 90s and 2000s). The first was to apply a decreasing trend from decade to decade using a ratio directly involving the production of asbestos contacting material (ACM) or dealing in ACMs, which was suggested by a previous study [15]. Data reanalysis using the available data without blanks from all three decades was conducted to build ratios between decades, and blanks were filled with the value computed using the ratio between the adjacent decades. Since almost all studies assessing the ambient asbestos concentration were conducted after the 1980s, the data before 1979 was estimated at double that of the 1980s which was a conservative value arrived at by the previous study [16]. The second method was to apply the same or constant values for the jobs (exposure groups) assuming the same working conditions through the decades under consideration, which in turn were related to asbestos-contaminated talc, processes using insulating felt or friction material, and working under/beside ACMs such as slate roofs.
2.2. Para-Occupational Exposure Estimation

A meta-analysis was performed on literature from Korea and the databases of other countries to determine the concentrations due to para-occupational exposure. A pooled analysis of studies until 2016 was conducted using PubMed and the Research Information Sharing Service (RISS, Daegu, Korea) with the terms of (asbestos) and (para-occupational or concentration or assessment or exposure or indirect exposure or air or lung cancer or malignant mesothelioma or asbestosis or diffuse pleural thickening or colleague at work or co-worker). From the 4260 articles selected using the search terms “asbestos” and (para-occupational or colleague at work or co-worker), 17 studies were included for the pooled analysis (Appendix A). Literature lacking asbestos concentration values (mean and standard deviation) was excluded from the pooled analysis.

2.3. Neighborhood Exposure from Occupational Asbestos Exposure Sources Using JEM

Only one study which conducted a simultaneous assessment of the inside and outside (by distance) of a factory was found despite an elaborate literature review [11]. Korea had no valid nationwide meteorological and geographic data before the 1990s. Therefore, we could not use simulation tools that needed specific meteorological data for past neighborhood exposure reconstruction from point environmental sources. Hence, we applied an exponential decay by distance model to formulate the required equations.

2.4. Neighborhood Exposure from NOA and Living under the Slate Roof House

Because NOA exposure estimations need specific location and exposure situations including agricultural activities, vehicle use, and other activities, previous studies regarding activity-based sampling (ABS) in NOA areas in Korea were pooled and analyzed. A total of 2194 articles located using the search terms (asbestos mine or naturally occurring asbestos) in RISS and Google Scholar until December 2019 were reviewed and 16 articles were shortlisted for analysis. Also, pooled analysis of living under slate roofs and non-occupational roof renovation activities were conducted. A total of 419 articles were identified using the search term “asbestos slate” in RISS, and Google Scholar until December 2019 and eight were selected after review.

2.5. Household Exposure from Occupationally Exposed Family Members

A pooled analysis of 3156 articles with studies until 2016 was conducted using PubMed and RISS with the terms of (asbestos) and (home or house or concentration or assessment or exposure or indirect exposure or secondhand or laundry or the wash or washing or family or familial or wife). The final 11 studies were included in the pooled analysis (Appendix B).

2.6. ELCRs

The airborne asbestos inhalation exposure algorithm was based on the 1992 PTI HRA [17]:

\[
EC = \frac{(Ca \times ET \times EF \times ED)}{AT}
\]

where, \(EC = \) Chronic Exposure Concentration (averaged over a 70-year lifetime) \([f/mL]\), \(Ca = \) Asbestos Concentration in fibers per cubic centimeter \([f/cc]\), \(ET = \) Exposure Time in hours/day, \(EF = \) Exposure Frequency in days/year, \(ED = \) Exposure Duration in years, \(AT = \) Average Time of 24 h/day \(\times 365\) days/year \(\times 70\) years (lifetime).

The ELCRs calculations were made using the equation described in EPA risk assessment guidance document [18].

\[
ELCR = EC \times URF
\]

where, \(ELCR = \) Excess Lifetime Cancer Risk, \(URF = \) Unit Risk Factor for inhalation of asbestos \([0.23 (f/mL)^{-1}]\).
3. Results

3.1. Korean Asbestos JEM Reconstruction

Results from the data reanalysis without blanks in any of the 3 decades of the recent Korean asbestos JEM are shown in Table 1. The mean concentrations (f/cc) 80s, 90s, and 2000s were 1.41, 0.57, and 0.06 with ratios of 1.00, 0.40, and 0.05 respectively.

To make conservative and simple calculations with the ratio of asbestos concentrations between the 80s and ~1979 as 1.0 vs. 2.0, we used the ratios of ~1979:80:90:2000~ as 2:1:0.5:0.05. Filling of the jobs (exposure groups) directly involved in the production of ACMs in the recent Korean asbestos JEM was done using the decreasing ratio by decades. Other jobs (exposure groups) were filled with the same data as adjacent values. The final reconstructed Korean asbestos JEM is shown in Appendix C (reconstructed Korean asbestos JEM).

Table 1. Asbestos concentrations of exposure groups without blanks in any of the 3 decades of recent Korean asbestos job-exposure matrix (JEM).

| Exposure Group (EG) | Industry (KSIC, 2007) | Occupation (KSOC, 7th) | Concentration (f/cc) |
|---------------------|-----------------------|------------------------|---------------------|
| EG9                 | 17129                 | Paper Machine Operators| 0.8097              |
| EG22                | 20302                 | Plastic Products Production Machine Operators n.e.c. | 0.8610 |
| EG39                | 21911                 | Mineral Ore and Stone Processing Machine Operators | 0.4600 |
| EG44                | 23994                 | Textile Production and Processing Machine Operators | 7.4800 |
| EG52                | 23994                 | Cement and Mineral Products Production Machine Operators | 1.700 |
| EG89                | 30399                 | Automobile Parts Assemblers n.e.c. | 0.4200 |
| EG91                | 31114                 | Ship Assemblers | 1.200 |
| EG128               | 85                    | School Teachers | 0.0004 |
| EG135               | 95119 (50130)         | Ship Mechanics | 0.2300 |
| EG139               | 95212                 | Automobile Mechanics | 0.9300 |

Mean (SD) 1.4120 (2.1890) (0.5659 (0.7986) (0.0641 (0.0573)

| Ratio |
|-------|
| 1.0   |
| 0.5   |
| 0.05  |

3.2. Para-Occupational Exposure Estimation

Eleven percent of the direct occupational exposure was the para-occupational exposure level as shown by the pooled analysis. When the JEM of the directly exposed job (exposure group) was known, then 11% for indirect exposure in the same workplace during the period could be applied.

3.3. Neighborhood Exposure from Occupational Asbestos Exposure Sources by Distance

Mean air concentrations inside and outside a factory were 2.4003 f/cc and 0.0601 f/cc (SD 0.03454 f/cc), and outside concentration was 2.5% (SD 1.1%) of the inside reading. The exponential decay by distance model was recalculated using the previous study and was based on the equation below [11]. The constant k was 6.834 with 95% confidence interval of 3.466–10.222 (R² = 0.81) (Figure 1):

\[ C_d = C_0 \times e^{-kd} \]

\[ C_d/C_0 = e^{-kd} \]
where, $d$: the distance (km), $C_d$: the asbestos concentration at distance $d$ (f/cc), $C_0$: the asbestos concentration at distance 0 (f/cc), $k$: the overall fiber decay constant = 6.834.

When the inside concentration of a specific place at a specific time was known, the $C_0$ would be estimated as 2.5% of the inside concentration, and $C_d$ might be estimated by the above exponential decay equation. When the inside concentration was unknown, the revised JEM could be used.

![Figure 1. Exponential decay model of ratio $C_d/C_0$ in ambient air by distance. Where, $d$: the distance (km), $C_d$: the asbestos concentration at distance $d$ (f/cc), $C_0$: the asbestos concentration at distance 0 (f/cc).](image)

3.4. Neighborhood Exposure from NOA and Living under the Slate Roof House

When the specific location and activities of a person in the NOA areas were known, the specific concentrations acquired by this study could be applied. Otherwise, the representative value of pooled analysis could be applied. The mean concentrations (f/cc) were $2.28 \times 10^{-3}$ for outdoor, $4.65 \times 10^{-5}$ for indoor, $1.95 \times 10^{-2}$ for transportation activity, $4.44 \times 10^{-2}$ for agricultural activity, and $4.68 \times 10^{-2}$ for daily life activity in the NOA area. Estimated data according to the hours of staying home and by age could be applied to the person who had lived in the NOA area or under a slate roof house. Indoor and outdoor asbestos concentrations from living in a slate roof house were $1.73 \times 10^{-6}$ and $2.70 \times 10^{-8}$, respectively.

3.5. Household Exposure from an Occupationally Exposed Family Member

One percent of the occupational exposure from exposed family members was the household exposure level as per the pooled analysis. When the JEM of the exposed family member and the cohabitant period were known, then the 1% level during the period could be applied.

3.6. Cancer Risk Calculation and Risk Grade Determination

The ELCRs calculations were made using below equation.

$$ ELCR = \sum_{i=1}^{6} (EPC_i \times TWF_i \times IUR_i) $$

where, $EPC = \text{Exposure Point Concentration}$, $TWF = \text{Time Weight Factor}$, $IUR = \text{Inhalation Unit Risk}$ [0.23 (f/mL)$^{-1}$], $i = 1$ (occupational exposure), 2 (para-occupational exposure), 3 (neighborhood exposure from occupational exposure sources by distance) 4 (neighborhood exposure from naturally occurring asbestos, NOA), 5 (neighborhood exposure from NOA and Living under the Slate Roof House).
exposure living under the slate roof house), 6 (household exposure from an occupationally exposed family member).

Final risk might be divided into four groups (with ELCRs) of very high ($1.0 \times 10^{-4} \leq \text{ELCR}$), high ($1.0 \times 10^{-5} \leq \text{ELCR} < 1.0 \times 10^{-4}$), moderate ($1.0 \times 10^{-6} \leq \text{ELCR} < 1.0 \times 10^{-5}$), and low ($\text{ELCR} < 1.0 \times 10^{-6}$).

4. Discussion

The mean concentrations of JEM in 1980', 1990', and 2000~ of this study were 1.41, 0.57, and 0.06, which were comparable with the results of previous studies [7,15,19]. The occupational exposure in Korea decreased sharply around the years 1990, 1997, and 2006, when asbestos was added to the list of designated special chemicals, a ban was imposed on the use of amosite and crocidolite, and a total ban on asbestos was imposed. Hence the grouping of 4 decades could be termed reasonable. Although Korea had produced asbestos since 1930', no exposure data including from unpublished sources was found before 1984. We estimated a two-fold higher occupational exposure before 1979 as compared to 1980' based on a previous study which estimated occupational exposure concentration as 11.0~92.4 f/cc in 1975 which was 1.8~5-fold higher than that of 1995 [16]. Also considering the suggestion of $-6.5$~$-7.7\%$ annual percentage change from retrospective occupational asbestos exposure estimation studies, a two-fold estimation of $1979$ compared to $1980'$ in this study may be a conservative estimate [20]. As there was a sharp decrease in occupational exposure related to the primary asbestos industry which dealt directly with raw asbestos or produced ACMs [15], we estimated the value to remain constant to fill in the missing data for exposure under/around ACMs.

We could not perform pooled analysis for the estimation of environmental asbestos dispersion because only a few studies were conducted on environmental ambient asbestos concentration by distance from occupational exposure sources and that too without simultaneous assessment of both the inside and outside concentrations [21–23]. Previous studies were conducted over different periods with different atmospheric conditions in countries like Germany, Taiwan, and Indonesia. Due to the plausible meteorological differences between those studies and Korean conditions, it was not possible to use that data in the pooled analysis. The Ministry of Environment of Korea has conducted health risk assessments for the neighborhoods around former asbestos mines including NOA areas, factories including shipyards, and dense slate roof areas [24]. Hence exposure estimations of neighborhood exposure from NOA and slate roofs are available. However, the NOA and weathering situation of slate roofs may be different depending on land use and the local atmospheric conditions. Hence, we have used Korean data only for neighborhood exposure from NOA and slate roof.

The first limitation of this study is its generalizability. Due to the sparsity of data, the analysis was limited to the few available studies and the results cannot be generalized. This problem is specific to the neighborhood exposure estimation by distance from occupational exposure sources. The estimation of emission and dispersion from occupational sources to the neighborhood environment requires simultaneous assessment, strong motivation, and support from the central and municipal governments and academics in the areas of both occupational and environmental health. The fact that until 2019 sixty-six countries had banned the production, use, and trade of asbestos makes further studies difficult. In addition to the above, the availability of data from only a small number of countries makes it difficult to apply this result to countries other than Korea, which is unique in having NOA and slate roofs. The second limitation is the validity issue.

While this study was aimed at developing a methodology for assessment, it could not be validated. This is the first attempt to the best of the author’s knowledge, at this kind of comprehensive past exposure estimation. Hence, validity tests using various data including real assessment or experimental studies, and matching with patient or compensation data is necessary. The third limitation is applicability. Comprehensive past exposure reconstructions need a foundation of comprehensive databases (DB) including
JEM and national exposure sources. Not many countries would attempt to build this DB. Also, the use of historical addresses and mobile exposure sources would need complicated calculation processes involving matching the geographical information system (GIS) and the above DB, which in turn will need the development of an appropriate computerized program.

This is one of the very few attempts that have been made to estimate the past asbestos exposure via almost all the possible routes. Identifying occupational, para-occupational, neighborhood, residence in an NOA area or under a slate roof, and household exposures might not only be used for epidemiologic purposes and compensation but will also help the public to focus on future risk prevention. The study results suggest the need and direction for further research to overcome the limitations stated above. This study also shows the need for a total ban on asbestos by describing the possible routes of exposure for ordinary people who did not directly deal in or with asbestos.

5. Conclusions

A nationwide past asbestos exposure assessment method for Korea was developed. The past occupational exposure reconstruction was conducted by rebuilding the previous general population JEM. Para-occupational and household exposure estimation were based on the pooled analysis of data from other countries as well as Korea. Because of meteorological differences, exposure from NOA and slate roof were estimated by a pooled analysis of Korean data only. The neighborhood exposure from occupational sources by distance was estimated by the exponential decay model. For improved generalizability, validity, and applicability of the proposed method, further studies on each route with real assessments and experiments are required. Further research on comparisons of this comprehensive estimation via various routes with other types of data including patient data and compensations is also required.

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**Conflicts of Interest:** The authors declare no conflict of interest.
Appendix A. Flow of the Selection Process of Studies for Pooled Analysis of Para-occupational Exposure

Searched studies from the databases (n=4260) : RISS (n=2610), PubMed (n=1650)

Articles remaining after excluding duplicates (n=4123) : RISS (n=2610), PubMed (n=1513)

Articles remained, Title reviews (n=392) : RISS (n=72), PubMed (n=320)

Articles remained, Abstract reviews (n=254) : RISS (n=58), PubMed (n=196)

Full text reviews (n=217) : RISS (n=34), PubMed (n=183)

Include by reference (n=2)

Studies included in the final analysis (n=17) : RISS (n=4), PubMed (n=13)
Appendix B. Flow of Selection Process of Studies for Pooled Analysis of Household Exposure from Occupationaly Exposed Family Members

Searched studies from the databases (n=3156) : RISS (n=2610), PubMed (n=546) → Duplicates (n=144)

Articles remaining after excluding duplicates (n=3012) : RISS (n=2610), PubMed (n=402) → Exclude according to the inclusion and exclusion criteria (n=2778)

Articles remained, Title reviews (n=234) : RISS (n=72), PubMed (n=162) → Exclude according to the inclusion and exclusion criteria (n=117)

Articles remained, Abstract reviews (n=117) : RISS (n=50), PubMed (n=67) → Exclude according to the inclusion and exclusion criteria (n=30)

Full text reviews (n=87) : RISS (n=34), PubMed (n=53) → Exclude according to the inclusion and exclusion criteria (n=77)

Include by reference (n=1)

Studies included in the final analysis (n=11) : RISS (n=1), PubMed (n=10)

Appendix C. Reconstructed Korean Asbestos Job Exposure Matrix

| Exposure Group (EG) | Industry (KSIC, 2007) | Occupation (KSOC, 7th) | Concentration (f/cc) |
|---------------------|-----------------------|------------------------|----------------------|
|                     | Code | Name                          | Code | Name                          | 1979  | 1980s | 1990s | 2000s |
| EG1                 | 07290 | Mining of Other Non-metal Ores n.e.c. | 91002 | Mining Laborers               | 0.47000 | 0.23500 | 0.11750 | 0.01175 |
| EG2                 | 07290 | Mining of Other Non-metal Ores n.e.c. | 83121 | Chemical Material Grinding and Mixing Machine Operators | 5.88000 | 2.94000 | 1.47000 | 0.14700 |
| EG3                 | 07290 | Mining of Other Non-metal Ores n.e.c. | 78412 | Quarrymen                     | 0.00600 | 0.00600 | 0.00600 | 0.00600 |
| EG4                 | 10301 | Processing and Preserving of Fruit and Vegetables, Pickled Food | 71052 | Side Dish Makers               | 0.01300 | 0.01300 | 0.01300 | 0.01300 |
| EG5                 | 13102 | Spinning of wool               | 8211  | Textile Processing Machine Operators | 0.74000 | 0.74000 | 0.74000 | 0.74000 |
| EG6                 | 13213 | Weaving of Man-Made Fiber Fabrics | 82211 | Weaving Machine Operators      | 1.52000 | 1.52000 | 1.52000 | 1.52000 |
| EG   | Code | Description                                      | NAICS Code |描述 | 2011 | 2012 | 2013 | 2014 |
|------|------|-------------------------------------------------|------------|-----|------|------|------|------|
| EG7  | 13993| Manufacture of Special Yarns and Tire Cord Fabrics | 8211       | 表面处理机操作员 | 0.07300 | 0.07300 | 0.07300 | 0.07300 |
| EG8  | 15219| Manufacture of Other Footwear                   | 721        | 表面处理机操作员 | 0.02580 | 0.02580 | 0.02580 | 0.02580 |
| EG9  | 17129| Manufacture of Other Paper and Paperboard        | 89132      | 纸机操作员 | 0.80970 | 0.80970 | 0.00940 | 0.00470 |
| EG10 | 17129| Manufacture of Other Paper and Paperboard        | 8914       | 纸机操作员 | 1.61000 | 1.61000 | 1.61000 | 1.61000 |
| EG11 | 17221| Manufacture of Paper Sacks and Paper Bags        | 84219      | 涂装机操作员 | 0.11250 | 0.11250 | 0.11250 | 0.11250 |
| EG12 | 17222| Manufacture of Paperboard Boxes and Containers   | 89141      | 涂装机操作员 | 0.45180 | 0.45180 | 0.45180 | 0.45180 |
| EG13 | 17222| Manufacture of Paperboard Boxes and Containers   | 84219      | 涂装机操作员 | 1.51000 | 1.51000 | 1.51000 | 1.51000 |
| EG14 | 17902| Manufacture of Sanitary Paper Products           | 89144      | 纸制品操作员 | 0.11560 | 0.11560 | 0.11560 | 0.11560 |
| EG15 | 17909| Manufacture of Other Articles of Paper and Paperboard | 89190  | 木制品操作员 | 3.54400 | 3.54400 | 3.54400 | 3.54400 |
| EG16 | 20111| Manufacture of Basic Organic Petrochemicals     | 83219      | 化学品操作员 | 0.01030 | 0.01030 | 0.01030 | 0.01030 |
| EG17 | 424  | Interior and Building Completion                | 7824       | 构筑木工 | 0.46400 | 0.23200 | 0.11600 | 0.01160 |
| EG18 | 2030 | Manufacture of Synthetic Rubber and of Plastics in Primary Forms | 8312 | 化工原料操作员 | 0.11280 | 0.11280 | 0.11280 | 0.11280 |
| EG19 | 20302| Manufacture of Synthetic Resin and Other Plastic Materials | 83121 | 化工原料操作员 | 1.06000 | 1.06000 | 1.06000 | 1.06000 |
| EG20 | 20302| Manufacture of Synthetic Resin and Other Plastic Materials | 83124 | 化工原料操作员 | 0.73000 | 0.73000 | 0.73000 | 0.73000 |
| EG21 | 20302| Manufacture of Synthetic Resin and Other Plastic Materials | 84219 | 涂装机操作员 | 0.68940 | 0.68940 | 0.68940 | 0.68940 |
| EG22 | 20302| Manufacture of Synthetic Resin and Other Plastic Materials | 83239 | 涂装机操作员 | 1.72200 | 0.86100 | 0.04310 | 0.04310 |
| EG23 | 20421| Manufacture of General Paints and Similar Products | 83121 | 化工原料操作员 | 0.61880 | 0.61880 | 0.61880 | 0.61880 |
| EG24 | 20431| Manufacture of Surface-Active Agents            | 83213      | 洗涤剂操作员 | 2.45000 | 2.45000 | 2.45000 | 2.45000 |
| EG25 | 20493| Manufacture of Adhesives and Gelatin            | 83121      | 化工原料操作员 | 0.05450 | 0.05450 | 0.05450 | 0.05450 |
| EG26 | 20499 (20111)| Manufacture of All Other Chemical Products n.e.c. | 8329 | 涂装机操作员 | 0.01030 | 0.01030 | 0.01030 | 0.01030 |
| EG27 | 21300| Manufacture of Pharmaceutical Goods Other Than Medicaments | 83211 | 化工原料操作员 | 0.01600 | 0.01600 | 0.01600 | 0.01600 |
| EG28 | 211  | Manufacture of Rubber Products                  | 83239      | 涂装机操作员 | 0.10970 | 0.10970 | 0.10970 | 0.10970 |
| EG29 | 22111| Manufacture of Tires and Tubes                  | 83221      | 涂装机操作员 | 0.65800 | 0.65800 | 0.65800 | 0.65800 |
| EG30 | 22191| Manufacture of Industrial Un-vulcanized Rubber Products | 83229 | 橡胶制品操作员 | 0.96050 | 0.96050 | 0.96050 | 0.96050 |
| EG31 | 22199| Manufacture of Other Rubber Products n.e.c.     | 83222      | 橡胶制品操作员 | 0.01170 | 0.01170 | 0.01170 | 0.01170 |
| EG32 | 20301 | Manufacture of Synthetic Rubber | 83222 | Rubber Products Production Machine Operators | 0.46840 0.46840 0.46840 0.46840 |
| EG33 | 22232 | Manufacture of Packaging Plastics and Shipping Containers | 83231 | Plastic Catapulting Machine Operators | 0.00750 0.00750 0.00750 0.00750 |
| EG34 | 22250 | Manufacture of Foamed Plastic Products | 83239 | Plastic Products Production Machine Operators | 5.12000 |
| EG35 | 22299 | Manufacture of Other Plastic Products n.e.c. | 83239 | Plastic Products Production Machine Operators n.e.c. | 0.01200 0.01200 0.01200 0.01200 |
| EG36 | 20302 | Manufacture of synthetic resin and other plastic materials | 83239 | Plastic Products Production Machine Operators n.e.c. | 1.72400 0.86200 0.04310 0.04310 |
| EG37 | 23199 | Manufacture of All Other Glass and its Products n.e.c. | 84319 | Glass and Glass Products Machine Operators n.e.c. | 0.00650 0.00650 0.00650 0.00650 |
| EG38 | 23211 | Manufacture of Pottery and Ceramic Household or Ornamental Ware | 84321 | Pottery and Porcelain Products Production Machine Operators | 0.00640 0.00640 0.00640 0.00640 |
| EG39 | 23219 | Manufacture of Other Refractory Ceramic Products | 84319 | Glass and Glass Products Machine Operators n.e.c. | 0.06400 0.06400 0.06400 0.06400 |
| EG40 | 23229 | Manufacture of Other Refractory Ceramic Products | 84322 | Brick and tile molding machine operators | 0.06420 0.06420 0.06420 0.06420 |
| EG41 | 23299 | Manufacture of Other Refractory Ceramic Products | 84399 | Nonmetal Products Related Production Machine Operators n.e.c. | 0.06900 0.06900 0.06900 0.06900 |
| EG42 | 23239 | Manufacture of Other Structural Non-refractory Clay and Ceramic Products | 8432 | Clay Products Production Machine Operators | 0.00370 0.00370 0.00370 0.00370 |
| EG43 | 23249 | Manufacture of Cellulose Fiber Cement Products | 84331 | Cement and Lime Production Related Machine Operators | 0.01340 0.01340 0.01340 0.01340 |
| EG44 | 23295 | Manufacture of Concrete Roofing Tiles, Bricks and Blocks | 84322 | Brick and Tile Production Machine Operators | 0.05900 0.05900 0.05900 0.05900 |
| EG45 | 2391 | Cutting, Shaping and Finishing of Stone | 78230 | Construction Stonemasons | 1.18000 1.18000 1.18000 1.18000 |
| EG46 | 23919 | Manufacture of Stone Products for Construction | 84341 | Mineral Ore and Stone Processing Machine Operators | 0.46000 0.46000 0.74000 0.14500 |
| EG47 | 23992 | Manufacture of Abrasive Articles | 84392 | Brightener Production Machine Operators | 0.80700 0.80700 0.80700 0.56000 |
| EG48 | 7121 | Quarrying of Monumental and Building Stone | 84341 | Mineral Ore and Stone Processing Machine Operators | 0.91200 0.91200 0.91200 0.91200 |
| EG49 | 23994 | Manufacture of Asbestos, Mineral Wools and Other Similar Products | 821, 8221 | Textile Production and Processing Machine Operators | 14.96000 7.48000 2.55000 0.14000 |
| EG50 | 23994 | Manufacture of Asbestos, Mineral Wools and Other Similar Products | 83121 | Chemical Material Grinding and Mixing Machine Operators | 0.06000 0.06000 0.06000 0.06000 |
| EG51 | 23994 | Manufacture of Asbestos, Mineral Wools and Other Similar Products | 84159 | Metal Processing Machine Operators n.e.c. | 0.02500 0.02500 0.02500 0.02500 |
| EG52 | 23994 | Manufacture of Asbestos, Mineral Wools and Other Similar Products | 84322 | Brick and Tile Production Machine Operators | 0.03000 0.03000 0.03000 0.03000 |
| EG53 | 23994 | Manufacture of Asbestos, Mineral Wools and Other Similar Products | 8433 | Cement and Mineral Products Production Machine Operators | 3.40000 1.70000 0.78000 0.01800 |
| Code | Description                                                                 | NAICS Code | Nonmetal Products Related Production Machine Operators n.e.c. |
|------|------------------------------------------------------------------------------|------------|-------------------------------------------------------------|
| EG53 | Manufacture of Other Unclassified Non-metallic Minerals n. e. c.              | 84399      | 0.06900 0.06900 0.06900 0.06900                              |
| EG54 | Manufacture of Other Basic Iron and Steel (Manufacture of Basic Iron)        | 84141      | Ore and Metal Furnace Operators                              |
|      | (24111)                                                                      |            | 0.00820 0.00820 0.00820 0.00820                              |
| EG55 | Manufacture of Hot Rolled, Drawn and Extruded Iron or Steel Products         | 84151      | Rolling Mill Operators                                       |
|      |                                                                              |            | 0.04000 0.04000 0.04000 0.04000                              |
| EG56 | Cast of Iron and Steel                                                       | 84110      | Metal Casting Machine Operators                              |
|      |                                                                              |            | 3.08000 1.54000 0.77000 0.07700                              |
| EG57 | Manufacture of Other Structural Metal Products                               | 84213      | Metal Product Painting Machine Operators                    |
|      |                                                                              |            | 0.21130 0.21130 0.21130 0.21130                              |
| EG58 | Manufacture of Powder Metallurgical Products                                | 84159      | Metal Processing Machine Operators n.e.c.                    |
|      | (25999)                                                                      |            | 0.11200 0.05600 0.02800 0.00280                              |
| EG59 | Forging of Metal/Manufacture of Basic Metal Products                         | 74130      | Forge Hammer smiths and Forging Press Workers                |
|      | (24)                                                                         |            | 0.00800 0.00800 0.00800 0.00800                              |
| EG60 | Manufacture of Metal Pressed and Stamped Products                            | 84151      | Rolling Mill Operators                                       |
|      |                                                                              |            | 0.00670 0.00670 0.00670 0.00670                              |
| EG61 | Heat Treatment of Metals                                                     | 84155      | Metal Heat Treatment Furnace Operators                       |
|      |                                                                              |            | 0.03370 0.03370 0.03370 0.03370                              |
| EG62 | Coating and Similar Treatment of Metals                                      | 84229      | Plating and Metal Spraying Machine Operators n.e.c.          |
|      |                                                                              |            | 0.11710 0.11710 0.11710 0.11710                              |
| EG63 | Manufacture of Saws, Saw Blades and Interchangeable Tools                    | 74110      | Die and Mold Makers                                         |
|      |                                                                              |            | 0.00860 0.00860 0.00860 0.00860                              |
| EG64 | Manufacture of Other Electronic Valves, Tubes and Electronic Components n.e.c.| 86321      | Electronic Parts Production Equipment Operators              |
|      |                                                                              |            | 0.01060 0.01060 0.01060 0.01060                              |
| EG65 | Manufacture of Broadcasting and Wireless Telecommunication Apparatuses       | 86409      | Electrical, Electronic Parts and Products Assembler n.e.c.   |
|      |                                                                              |            | 0.02800 0.02800 0.02800 0.02800                              |
| EG66 | Manufacture of Other Sound Equipment                                         | 86402      | Audio-Visual Equipment Assemblers                            |
|      |                                                                              |            | 0.02200 0.02200 0.02200 0.02200                              |
| EG67 | Manufacture of Industrial Process Control Equipment                          | 76224      | Electrical Control Unit Fitters and Mechanics                |
|      |                                                                              |            | 0.00100 0.00100 0.00100 0.00100                              |
| EG68 | Manufacture of Industrial Process Control Equipment                          | 85101      | Lathe Machine Operators                                     |
|      |                                                                              |            | 0.00200 0.00200 0.00200 0.00200                              |
| EG69 | Manufacture of Electric Motors and Generators                                | 86401      | Electrical Equipment Assemblers                             |
|      |                                                                              |            | 0.01430 0.01430 0.01430 0.07180                              |
| EG70 | Manufacture of Other Electric Motors, Generators and Transformers            | 85109      | Metal Work Machinery Operators n.e.c.                        |
|      |                                                                              |            | 0.06460 0.06460 0.06460 0.07540                              |
| EG71 | Manufacture of Other Electric Motors, Generators and Transformers            | 8610, 86311| Power Generation and Distribution Equipment Operators, Electrical Parts Production Equipment Operators |
|      |                                                                              |            | 0.00400 0.00400 0.00400 0.00400                              |
| EG72 | Manufacture of Insulated Wire and Cable                                      | 86402      | Audio-Visual Equipment Assemblers                            |
|      |                                                                              |            | 0.35790 0.35790 0.35790 0.35790                              |
| EG73 | Manufacture of Insulated Codes Sets and Other Conductors for Electricity     | 86401      | Electrical Equipment Assemblers                             |
|      |                                                                              |            | 0.12450 0.12450 0.12450 0.12450                              |
| EG74 | Manufacture of Electric Lamps and Electric Bulbs                            | 86312      | Electrical Products Production Equipment Operators          |
|      |                                                                              |            | 0.20310 0.20310 0.20310 0.20310                              |
| EG75 | Manufacture of General Electric Lighting Fixture                             | 86401      | Electrical Equipment Assemblers                             |
|      |                                                                              |            | 0.01970 0.01970 0.01970 0.01970                              |
| Code | Industry Description                                                                 | NAICS Code | Standard Industry Description                                                                 | Employment | Wages |
|------|---------------------------------------------------------------------------------------|------------|---------------------------------------------------------------------------------------------|------------|-------|
| EG76 | Manufacture of Other Domestic Electric Appliances                                      | 86312      | Electrical Products Production Equipment Operators                                          | 0.00500    | 0.00500|
| EG77 | Manufacture of Pumps and Compressors                                                  | 89904      | Air Compressor Operators                                                                    | 0.00500    | 0.00500|
| EG78 | Manufacture of Taps, Valves and Similar Products                                       | 8510       | Metal Work Machinery Operators                                                              | 0.55600    | 0.55600|
| EG79 | Manufacture of Other Work trucks, Lifting and Handling Equipment                      | 8544       | General Machinery Assemblers                                                               | 0.09000    | 0.09000|
| EG80 | Manufacture of Agricultural and Forestry Machinery                                    | 83239      | Plastic Products Production Machine Operators n.e.c.                                      | 0.00260    | 0.00260|
| EG81 | Manufacture of Agricultural and Forestry Machinery                                    | 85442      | Agricultural Machinery Assemblers                                                          | 0.04630    | 0.04630|
| EG82 | Manufacture of Machinery for Food, Beverage and Tobacco Processing                  | 811        | Food Processing Related Machine Operators                                                   | 0.00780    | 0.00780|
| EG83 | Manufacture of Other Special Purpose Machinery, n.e.c.                               | 85441      | Industry Machinery Assemblers                                                              | 0.11330    | 0.11330|
| EG84 | Manufacture of Passenger Motor Vehicles                                               | 85410      | Automobile Assemblers                                                                     | 0.02330    | 0.02330|
| EG85 | Manufacture of Parts and Accessories for Motor Vehicles and Engines                   | 74130      | Forge Hammersmiths and Forging Press Workers                                                | 0.00110    | 0.00110|
| EG86 | Manufacture of Parts and Accessories for Motor Engines                                | 85421      | Automobile Engine Assemblers                                                              | 0.28000    | 0.14000|
| EG87 | Manufacture of Other Parts and Accessories for Motor Vehicles n. e. c.                | 75105      | Automobile Paint Mechanics                                                                | 1.05000    | 1.05000|
| EG88 | Manufacture of Other Parts and Accessories for Motor Vehicles n. e. c.                | 85429      | Automobile Parts Assemblers n.e.c.                                                         | 0.18000    | 0.18000|
| EG89 | Manufacture of Other Parts and Accessories for Motor Vehicles n. e. c.                | 85429      | Automobile Parts Assemblers n.e.c.                                                         | 0.84000    | 0.42000|
| EG90 | Building of steel ships                                                                | 75220      | Ship Mechanics                                                                              | 0.52000    | 0.26000|
| EG91 | Manufacture of Sections for Ships                                                     | 85432      | Ship Assemblers                                                                             | 2.46000    | 1.23000|
| EG92 | Manufacture of Aircraft Parts and Accessories                                         | 85433      | Aircraft Assemblers                                                                        | 0.09500    | 0.09500|
| EG93 | Manufacture of Musical Instruments                                                    | 73031      | Musical Instrument Makers and Repairers                                                     | 0.01850    | 0.01850|
| EG94 | Other Manufacturing n.e.c.                                                             | 83124      | Chemical Material Distiller and Reactor Operators                                           | 0.83550    | 0.83550|
| EG95 | Electric Power Generation                                                             | 8610       | Power Generation and Distribution Equipment Operators                                      | 0.00360    | 0.00360|
| EG96 | Electric Power Generation                                                             | 23519      | Machine Engineers and Researchers n.e.c.                                                    | 0.00360    | 0.00360|
| EG97 | Collection, Purification and Distribution of Water to Household                       | 8810       | Water Treatment Plant Operators                                                            | 0.06600    | 0.06600|
| EG98 | Hazardous Waste Collection                                                            | 8820       | Recycling Machine and Incinerator Operators                                                 | 0.00310    | 0.00310|
| EG99 | Hazardous Waste Collection                                                            | 91001      | Construction Laborers                                                                       | 0.00500    | 0.00500|
| EG100| Waste Treatment Services                                                               | 8820       | Recycling Machine and Incinerator Operators                                                 | 0.01600    | 0.01600|
| EG101| Disposal of Hazardous Waste                                                           | 88209      | Recycling Machine and Incinerator Operator n.e.c.                                          | 0.01300    | 0.01300|
| Code  | Number | Description                                                                 | NAICS  | Industry Description                                                                 | Q001 | Q002 | Q003 | Q004 |
|-------|--------|------------------------------------------------------------------------------|--------|--------------------------------------------------------------------------------------|------|------|------|------|
| EG102 | 41224  | Installation of Environmental Hygiene Treatment Appliances                    | 88209  | Recycling and Incinerator Operator n.e.c.                                           | 0.0180 | 0.0180 | 0.0180 | 0.0180 |
| EG103 | 41112  | Apartment Building Construction                                               | 772    | Broadcasting and Telecommunications Equipment Related Fitters and Repairers         | 0.0390 | 0.0390 | 0.0390 | 0.0390 |
| EG104 | 41229  | Other Civil Engineering Construction                                          | 23123  | Building Construction Engineers                                                      | 0.00420 | 0.00420 | 0.00420 | 0.00420 |
| EG105 | 42110  | Wrecking and Demolition of Buildings and Other Structures                    | 78293  | Building Demolition Workers                                                          | 0.16960 | 0.08480 | 0.04240 | 0.00430 |
| EG106 | 42121  | Excavating and earthmoving                                                   | 78499  | Mining and Civil Engineering Related Workers n.e.c.                                 | 0.00060 | 0.00060 | 0.00060 | 0.00060 |
| EG107 | 42132  | Steel Reinforcing and Reinforced Concrete Works                              | 7822   | Concrete Placers and Assemblers                                                     | 0.00100 | 0.00100 | 0.00100 | 0.00100 |
| EG108 | 42134  | Pavement Works                                                               | 7836   | Construction Painters                                                               | 0.00100 | 0.00100 | 0.00100 | 0.00100 |
| EG109 | 42137  | Scaffolding and Frame Works                                                  | 78291  | Scaffolders                                                                          | 0.02100 | 0.02100 | 0.02100 | 0.02100 |
| EG110 | 4521   | Sale of Motor Vehicle New Parts and Accessories                              | 52129  | Operations of Vehicle Parking Facilities                                            | 2.84000 | 1.42000 | 0.71000 | 0.00000 |
| EG111 | 471    | Retail Sale in Non-Specialized Stores                                        | 5211   | Store Salespersons n.e.c.                                                            | 0.00800 | 0.00800 | 0.00800 | 0.00290 |
| EG112 | 47119  | Retail Sale in Other Non-Specialized Large Stores                            | 5211   | Owners and Supervisors of Small Stores                                              | 0.00530 | 0.00530 | 0.00530 | 0.00530 |
| EG113 | 501    | Sea and Coastal Water Transport                                              | 8760   | Ship Workers and Related Workers                                                     | 0.00100 | 0.00100 | 0.00100 | 0.00100 |
| EG114 | 50122  | Coastal freight water transport                                              | 92101  | Freight Workers and Related Workers                                                  | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| EG115 | 52911  | Supporting, Railway Transport Activities                                     | 31262  | Railway Transport Clerks                                                             | 0.00800 | 0.00800 | 0.00800 | 0.00290 |
| EG116 | 79211/ | Supporting, Railway Transport Activities                                     | 3252   | Locomotive and Electric Train Mechanics                                             | 0.07200 | 0.03600 | 0.01800 | 0.00180 |
| EG117 | 52911  | Supporting, Railway Transport Activities                                     | 75232  | Railroad train mechanics                                                            | 1.48400 | 0.74200 | 0.37100 | 0.03710 |
| EG118 | 52915  | Operation of Vehicle Parking Facilities                                      | 52132  | Passenger Ticket Salespersons                                                       | 0.00390 | 0.00390 | 0.00390 | 0.00390 |
| EG119 | 59141  | Motion Picture Exhibition                                                     | 28399  | Drama, Film and Video Related Workers n.e.c.                                        | 0.00600 | 0.00600 | 0.00600 | 0.00600 |
| EG120 | 6022   | Broadcasting via Cable, Satellite and Other Broadcasting                     | 2250   | Telecommunication and Broadcast Transmissions Equipment Technicians                 | 0.00500 | 0.00500 | 0.00500 | 0.00500 |
| EG121 | 68211  | Residential Property Management                                              | 85201  | Cooler and Heater Related Machine Operators                                         | 0.00200 | 0.00200 | 0.00200 | 0.00200 |
| EG122 | 95119  | Other Maintenance and Repair Services of General Machinery                   | 75351  | Building Boiler Fitters and Mechanics                                               | 0.22107 | 0.11054 | 0.05527 | 0.05553 |
| EG123 | 70129  | Research and Experimental Development on Other Engineering                   | 13114  | Engineering Research Managers                                                       | 0.11910 | 0.11910 | 0.11910 | 0.11910 |
| EG124 | 72122  | Environmental Consulting and Related Engineering Services                    | 15301  | Environmental Service Related Managers                                              | 0.00100 | 0.00100 | 0.00100 | 0.00100 |
| EG125 | 74100  | Business Facilities Support Management Services                              | 12090  | Public and Business Administration Managers                                         | 0.00150 | 0.00150 | 0.00150 | 0.00150 |
| EG126 | 75290  | Other Tourist Assistance and Reservation Services                            | 52132  | Passenger Ticket Salespersons                                                       | 0.01000 | 0.01000 | 0.01000 | 0.01000 |
| EG127 | 84213  | Regulation of Activities of Environment Affairs                              | 21125  | Astronomy and Space Science Researchers                                             | 0.47050 | 0.47050 | 0.47050 | 0.47050 |
| EG128 | 85     | Education                                                                   | 252    | School Teachers                                                                      | 0.00030 | 0.00036 | 0.00300 | 0.00380 |
| EG129 | 85501  | General Subject Educational Institute                                        | 25419  | Liberal Arts and Language Instructors n.e.c.                                        | 0.00700 | 0.00700 | 0.00700 | 0.00700 |
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