La Medicina del Lavoro

Reviews, Commentaries, Perspectives

Med. Lav. 2024; 115 (6): e2024042
DOI: 10.23749/mdl.v115i6.15453

Human Exposure to Asbestos in Central Asian Countries and Health Effects: A Narrative Review

Zhyldyz Kurzhunbaeva[1], Kenesh Dzhusupov[2], Andrea Spinazzè[3], Silvia D. Visonà[4,*], Cholpon Sulaimanova[2], Omor Kasymov[5], Elena Belluso[6], Claudio Colosio[7]

[1]Department of Health Sciences; Course of Research Doctorate in Public Health Sciences, University of Milan, Milan, Italy
[2]Department of Public Health, International Higher School of Medicine, Bishkek, Kyrgyz Republic
[3]Department of Science and High Technology, University of Insubria, Como, Italy
[4]Department of Public Health, Experimental and Forensic Medicine, University of Pavia, Pavia, Italy
[5]National Institute of Public Health under the Ministry of Health of the Kyrgyz Republic, Bishkek, Kyrgyz Republic
[6]Deparment of Earth Sciences and Interdepartmental Centre for Studies on Asbestos and Other Toxic Particulates, University of Turin, Turin, Italy
[7]Post Graduate School in Occupational Health of the University of Milano, Italy

Keywords: Asbestos; Chrysotile; Asbestos-Related Diseases; Exposure Assessment; Mesothelioma

Summary

The discovery of the detrimental effects of asbestos on human health came long after its widespread use, with the first scientific evidence of asbestos-related diseases emerging in the late 19th and early 20th centuries. Despite efforts to ban its use, asbestos continues to be mined and used in Central Asia (as well as in Russia, China, and other countries). To gain a deeper understanding of the situation in Central Asia, we have conducted a review of scientific literature on the use of asbestos, exposure assessment, and health consequences of asbestos exposure in this geographic area. This review encompasses studies about exposure assessments, epidemiological data, and biochemical or clinical surveys conducted in Kazakhstan, Uzbekistan, Tajikistan, Turkmenistan, and Kyrgyzstan. A total of 18 articles met the inclusion criteria, and their content is summarised in this review, which represents the first attempt to systematically examine research on asbestos and its impact on the health of workers and the general population in Central Asia countries, including literature published in Russian and English. The findings here highlighted the substantial limitations of the currently available knowledge about the impact of asbestos on health in this geographical area.

1. Introduction

Asbestos is the name given to six silicate minerals: chrysotile (the only one belonging to the serpentines) and amphiboles (amosite, crocidolite, asbestos anthophyllite, asbestos tremolite, and asbestos actinolite) [1]. Asbestos has been considered a valuable resource in various industrial sectors for a long time owing to its exceptional physical and chemical properties. These properties include, but are not limited to, fire resistance, electrical, thermal, and acoustic insulation, and mechanical robustness. As such, asbestos has been extensively utilized in a wide range of manufactured goods, such as building materials (roofing, ceiling and floors, and asbestos cement products), automobile parts, heat-resistant fabrics, and the war industry [2].

Exposure to any form of asbestos poses an increased risk of developing asbestos-related diseases (ARDs) [3]. These diseases can be divided into

---

Received 11.11.2023 - Accepted 11.11.2024

*Corresponding Author: Silvia D. Visonà; e-mail: silviadamiana.visona@unipv.it

non-malignant conditions, such as pleural plaques and asbestosis, and malignant ones, lung cancer, pleural and peritoneal mesothelioma, laryngeal and ovarian cancer, and, with lower levels of evidence, other cancers [3, 4]. Malignant mesothelioma is a highly aggressive cancer arising from the mesothelial linings of pleural, pericardial, peritoneal, and testicular cavities [5]. It has given rise to clinical manifestations for several decades since the beginning of exposure [6, 7]. Different levels of exposure and risk exist, with certain occupations and proximity to asbestos mines or factories posing higher risks [7, 8].

Asbestos-related diseases cause around 255,000 deaths annually worldwide [9]. Many countries have banned asbestos production and use, aligning with the C162 Asbestos WHO reports published in 2006 and 2007, the Basel Convention [10, 11], and national prohibition laws [12]. Nevertheless, there are several countries, among which Russia, China, Kazakhstan, and India, who continue asbestos mining and use. Other countries, including Central Asia (CA), such as Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan, are still large importers and consumers of chrysotile, even if they do not have asbestos mines. On these bases, the present paper provides an overview of the existing knowledge on asbestos use, exposure, and consequences in CA (and precisely in Kyrgyzstan, Kazakhstan, Tajikistan, Uzbekistan, and Turkmenistan), aiming to understand the current situation in these countries, where asbestos-containing materials are still highly diffused.

2. METHODS

2.1. Data Sources and Search Strategy

We reviewed available publications to identify articles on asbestos and ARDs in CA countries. We searched international repositories (Google Scholar, PubMed, Web of Science, Scopus, and Elibrary.ru [13]) using the keywords reported in Table S1 in the Supplementary materials.

Articles published in English and Russian from 2008 to 2022 were collected as electronic publications. All references were imported into EndNote X20. The PRISMA Flow Diagram [14, 15] created a review flowchart. In addition, we used the Russian-language version of the Elibrary.ru database (an electronic library of scientific publications from Russia and CA countries integrated with the Russian Science Citation Index (RSCI) to search for all available Russian journals. Data were also collected from the Scientific Production Association 'Preventive Medicine' in Kyrgyzstan and the national statistical agencies of each CA country [16]. In addition, data was taken from open online sources, such as export and import statistics, production quantities, and data concerning the consumption of asbestos in CA [17].

2.2. Selection Criteria

During this search, we reviewed the articles by selecting them by title and abstract, then by full text and review results. After removing duplicate articles, we screened each study based on the inclusion and exclusion criteria.

The papers were included if they contained sufficient and relevant information concerning the following topics: asbestos, occupational and environmental exposure to asbestos, production, use of asbestos-containing products, asbestos-related diseases, and mesothelioma. They were included if they were available as complete texts, written in English or Russian, and focused on CA Countries.

The screening process and quality assessment of the selected articles were conducted separately (and double-checked) by different authors (ZK, KD, AS, CC) to reduce operator-related errors. The four investigators independently extracted the information from the included studies using a predefined datasheet (first author, geographic area, year of publication, industry sector, type of asbestos, and outcome). Articles that could not provide sufficient data or information or that were related to laboratory studies on asbestos in chemistry and geology sciences and studies published in languages other than English and Russian, reviews, and articles unavailable as full text were excluded from the study. Excluded studies were checked for any relevant information not delivered in the selected publications. Any disagreement or discrepancy in the study selection and data extraction processes was resolved by consensus among the authors.

2.3. Data Extraction

The full text of each study was categorized by its title, first author, date of publication, journal, study period, keywords, and strand use. This data was then used to build a database using an Excel spreadsheet.

3. Results

3.1. Data Acquisition and Analysis

In total, 105 relevant research articles were found using the repositories outlined in Figure S1 (Supplementary materials), which summarises the PRISMA [14, 15] flow diagram selection process.

The main findings of the selected articles were tabulated in a data extraction Excel form. Table S2 (Supplementary materials) summarises the study's key findings, the year of publication, and the language used. After applying the inclusion and exclusion criteria to all 105 articles, 18 papers were left (a summary is presented in Table S1). CA countries are former members of the Soviet Union; therefore, they predominantly publish in Russian (78% of the 18 selected articles were written in Russian). As for the country addressed, most of the studies (88.9%) concerned Kazakhstan. Only 5.6% concerned Kyrgyzstan, another 5.6% concerned Uzbekistan, and none concerned Turkmenistan and Tajikistan. The thematic content of the 18 articles can be summarised as follows:

- Only one reviewed paper [18] was about asbestos exposure in workplace environments.
- Only one paper [19] addresses outdoor air pollution from asbestos production.
- Nine studies [20–28] are based on biological samples from individuals working with asbestos and conducting clinical examinations, including biochemical and histological tests.
- Two studies [19, 29] contained additional information concerning asbestos dust pollution at the workplace.
- The other two [30, 31] described tests conducted on laboratory animals (rats).
- One [32] addressed Uzbekistan's economic and public health-related disadvantages of asbestos use.
- Three studies [23, 26, 30] concerned non-malignant ARDs.
- Two articles [19, 33] contained epidemiological studies on the links between mesothelioma and chrysotile asbestos.
- One article [34] focused on developing risk management strategies to minimize health risks in workers.
- Only one study [35] investigated the morbidity with temporary disability (MTD) among workers in the asbestos factory.

In addition to peer-reviewed journals, we also examined the occupational disease registries of the various CA countries, non-peer-reviewed reports, conference proceedings, and internal government documents, such as the report of the Scientific and Production Association "Preventive Medicine" under the Ministry of Health of the Kyrgyz Republic.

3.2. Overview of Asbestos Production and Corresponding Industries in CA Countries

Three countries—Russian Federation, China, and Kazakhstan—still produce more than 2 million metric tons of asbestos annually. Currently, 25 countries, including all the CA countries: Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan, consume at least 1,000 metric tons of asbestos annually (Table 1) [36].

3.2.1. Asbestos Mining and Producing Asbestos-Contained Commodities Industries in Kazakhstan.

Kazakhstan is the largest country in CA, with a population of 18,879,552 [37]. The country is rich in deposits of various minerals, including chrysotile. Today, Kostanay Minerals Enterprise (KME) is the only company mining asbestos in the country [38]. The KME works the Zhitikara chrysotile deposit in the Kostanay region and employs around 2,000 people. This deposit ranks fourth in the world in terms of reserves, and the company exports to other countries of CA and beyond. Annually, the KME produces over 200,000 tons of asbestos as a raw material [38]. In addition to this company, three linked companies within the mining industry produce

Table 1. Export and import of asbestos (excluding asbestos products) to CA countries from 2017-2021. Adapted from https://www.trademap.org/, accessed on 26.12.2022.

Years	Countries	Kazakhstan	Uzbekistan	Tajikistan	Turkmenistan	Kyrgyzstan
2017	Exported asbestos (tons)	182,304	0	0	0	0
	Imported asbestos (tons)	130	87,403	4,968	6,405	9,601
2018	Exported asbestos (tons)	184,830	0	0	0	0
	Imported asbestos (tons)	44	129,032	9,616	6,438	9,319
2019	Exported asbestos (tons)	217,839	0	0	0	0
	Imported asbestos (tons)	12	94,168	14,818	8,786	9,847
2020	Exported asbestos (tons)	209,784	0	0	0	15
	Imported asbestos (tons)	407	116,654	15,493	13,324	9,616
2021	Exported asbestos (tons)	232,366	0	0	0	0
	Imported asbestos (tons)	20	126,115	23,711	13,130	12,013

asbestos-cement goods, employing about 6,000 additional people [29].

3.2.2. Industries of Kyrgyzstan Produce Asbestos-Containing Commodities

Kyrgyzstan is another of the former Soviet republics in CA, with a population of 6.936,2 million [39]. The first enterprise in Kyrgyzstan to produce chrysotile-cement products is the Kant Pipe and Slate Enterprise (PSE) [40], which has been operating since 1967 and remains open today. The enterprise is located in Kant town, 22 km from the capital, Bishkek, and employs around 300 workers. Raw asbestos is imported from Kostanay Minerals JSC (Kazakhstan) and Ural Asbest OJSC [41] (Russia). Annually, the company sells 5 million units of asbestos-containing products. In 2020, a branch of Kant PSE was opened in the city of Kyzyl-Kyia, in the south of Kyrgyzstan, with a production capacity of 3.7 million units of 8-wave slate per year and employing around 150 workers. This production capacity is designed to meet the demand in the south of Kyrgyzstan, and it is exported to Uzbekistan and Tajikistan [40]. The second plant to open in Kyrgyzstan producing chrysotile products is Kant Kurulush LLC [42], founded in 2013 in the city of Kant in the north of Kyrgyzstan. They produce non-pressure pipes and couplings as well as 8-wave slate. The primary raw material used is Russian chrysotile (asbestos), imported from Ural Asbest OJSC, Russia [42].

3.2.3. Industries of Uzbekistan Producing Asbestos-Containing Commodities

Uzbekistan is the most highly populated country in the CA region, with a population of 36,024,946 [43]. In 2020, Uzbekistan imported $37 million worth of asbestos, making it the 3rd largest asbestos importer in the world. In the same year, asbestos was Uzbekistan's 132nd most imported commodity. Uzbekistan imports asbestos mainly from the following countries: Kazakhstan ($29.2 million); Russia ($7.63 million), China ($104 thousand), and Kyrgyzstan ($2.29 thousand) [44]. There are 44 enterprises in the country producing asbestos goods [45]. However, the total quantity of asbestos products manufactured by Uzbekistan is unknown.

3.2.4. Industries in Tajikistan Producing Asbestos-Containing Commodities

Tajikistan's population is around 9,700,000 [46]. In 2020, Tajikistan imported $6.19 million worth of asbestos, becoming the ninth-largest asbestos importer in the world. Asbestos is ranked 138th among Tajikistan's most imported commodities. Tajikistan imports asbestos mainly from Kazakhstan ($4.54 million) and China ($1.65 million) [44].

However, information regarding the number of enterprises producing asbestos products is not publicy available.

3.2.5. Industries in Turkmenistan Producing Asbestos-Containing Commodities

Turkmenistan has a population of 6,341,855 [47]. In 2020, it imported $4.52 million worth of asbestos, making it the 10th largest asbestos importer globally. In the same year, asbestos was Turkmenistan's 147th most imported commodity. Turkmenistan imports asbestos mainly from Kazakhstan ($4.52 million) [44]. Again, the number of enterprises using asbestos is unavailable.

3.3 Detailed Overview of the Results

3.3.1. Physical and Chemical Characteristics of Asbestos Used in CA

Ibraev and colleagues described the physical and chemical characteristics of chrysotile mined and extracted from Zhitikara ore [48]. The study used a scanning electron microscope (Tescan Vega\LSU) with an energy-dispersive spectroscopy microprobe (INCA-PentaFET-x3). Notwithstanding, the authors do not present any EDS spectra, only SEM images (compatible with pure chrysotile) and a table containing the percentage of elements included in the analyzed points. The results showed the different values of the outer diameter of the chrysotile fibers, which range from 94 to 167 nm (no data about the lengths of the fibers were presented).

3.3.2. Asbestos Concentrations in the Workplace and the Environment

Amanbekova and co-workers (2014) [29] found that the average daily dust concentration at workplaces in "Kostanay minerals" JSC in Kazakhstan was equal to 6 mg/m^3 in 2014, which was higher than the maximum permissible concentration (MPC) of Kazakhstan's legislation where the MPC is equal to 0,5 mg/m^3 (for dust containing more than 20% of asbestos) and 1 mg/m^3 (for dust containing less than 20% of asbestos) [49]; however, they did not specify whether the MPC of one-time exposure or average daily exposure, moreover there was no description of the measurement method used for determining the dust concentration. The following year (2015), Ibraev et al. [18] measured the level of dust in 2015 in the same industry; the average daily results ranged from 0.2 to 1 mg/m^3, which did not exceed the MPC limits of Kazakhstan. This study used a gravimetric method to measure the asbestos concentration. This method is considered obsolete for measuring asbestos contamination since it does not count only the number of asbestos fibers but the whole dust dust collected, thereby not providing a fiber-specific concentration.

Both studies did not mention the implementation of specific environmental control actions between 2014 and 2015. The decrease in reported dust levels by Ibraev et al. (2015) could imply some intervention to reduce dust levels. However, with explicit details, we can conclusively link the decrease in fiber concentration to any particular control measures.

The Centre for Environmental Medicine and Human Ecology also studied air pollution in one industry that produced asbestos-containing commodities (Kant PSE, Kyrgyzstan) from 2019 to 2020 [16]. In total, 340 measurements were made at 162 points during the day and 18 points at night. The dust content in the air was determined through the gravimetric method. The dust dispersion and particle size characteristics were determined using a light trinocular microscope equipped with an ocular micrometer and software (BioVision, Austria). According to the results of the study, the average daily dust level in the air at the workplaces varied from 1.34 mg/m^3 to 1.45 mg/m^3 [16], which exceeds the national regulations on acceptable MPC limits of dust containing asbestos in industries, where average daily MPC is equal to 0,5 mg/m^3 (for dust containing more than 20% of asbestos) and 1 mg/m^3 (for dust containing less than 20% of asbestos) [50]. The authors did not report the determination of weight concentrations of asbestos.

However, it should be noted that the studies' findings do not comply with the European Union's occupational exposure limits or Kazakhstan's or Kyrgyzstan's MPCs. Additionally, the gravimetric method is obsolete for measuring asbestos contamination since it is impossible to count the number of asbestos fibers (and thus obtain a quantitative and specific value for airborne asbestos concentrations) [3, 51].

Korotenko et al. (2011) studied the environmental emissions caused by Kant Pipe and Slate Enterprise (PSE) in Kyrgyzstan [19]. They highlighted that the industry released ten pollutants into the surrounding atmosphere, with 0.515 tonnes of asbestos-containing dust emitted in 2010. This amount of asbestos did not exceed the allowed annual emission of asbestos-containing dust in Kyrgyzstan, which is 1.47 tonnes. However, the authors did not elaborate further on their findings.

3.3.3. Research on Asbestos Industry Workers

3.3.3.1. Morbidity

Ibraev et al. (2014) [34] studied working conditions and health risks in chrysotile extraction at JSC "Kostanai Minerals", revealing hazard levels of 3.3-3.4 at the enrichment complex (EC) and 3.3 at mining and transport enterprises (MTE). Occupational disease rates were 55.9 per 10,000 workers at EC and 34.9 at MTE, with temporary morbidity causing 1127.3 days of incapacity at EC and 1144.6 days at MTE. The authors analyzed morbidity using the WHO's "International Classification of Diseases, Injuries, and Causes of Death" (1996) but did not specify the exact diseases, such as mesothelioma or lung cancer. However, the authors emphasized the need for strict chrysotile use control, safety standards, risk management, and preventive measures to protect workers' health and ensure compliance with safety regulations.

Ibraev et al. (2018) [35] investigated the temporary disability/morbidity among workers involved in chrysotile production at JSC "Kostanai Minerals," focusing on ore enrichment. Two groups were compared: control (administrative and technical workers, n=299) and main (ore preparation and enrichment workers, n=917). The control group faced fewer harmful factors, while the main group suffered high noise levels, dust exposure, and poor working conditions. Morbidity rates were higher in the main group, with men showing 21.2±2.2 cases of disability/morbidity and 514.1 days of incapacity per 100 workers, compared to 9.1±0.2 cases and 203.1 days in the control group. Women's rates were slightly lower but still significant. The main group's overall morbidity was 69.2±8.4 cases and 1127.3 days per 100 workers, versus 46.0±2.6 cases and 677.3 days in the control group. The highest morbidity was among workers with less than 9 years of experience, and respiratory diseases were the most common ailment. The study highlights the significant impact of production factors on worker health, with a higher morbidity level in the leading group, indicating the need for improved working conditions and health monitoring. Notably, the work did not address specifically asbestos-related diseases.

3.3.3.2. Radiological Findings

A study by Ibraev et al. (2008) examined 47 employees of Kostanay Minerals JSC in 2008 [23]. An X-ray examination of 20 workers with more than 20 years of work experience showed an increase in the vascular picture, minor perivascular and peribronchial pneumofibrosis in the median zones of the lungs in 60% of cases, and moderately expressed perivascular and peribronchial pneumofibrosis in the media zones in 13 cases (40%).

3.3.3.3. Pulmonary Function and Respiratory Findings (PFR)

In the same study, the respiratory function of these 47 employees was analyzed, revealing that six workers suffered from chronic bronchitis and disorders of pulmonary ventilation function. Twenty-five percent of cases among them had respiratory obstruction, with some cases also showing hypoxemia [23]. Interestingly, no cases of pulmonary restriction were observed.

Additional cytological examination of the nasal and oral epithelium of 65 workers [22] and 108 workers [27] of Kostanay Minerals JSC (2015) showed a high frequency of destructive changes of the cells of the nasal mucosa in samples of workers with occupational exposure from 5 to 20 years. In these studies, authors investigated cellular changes in the nasal mucosa and buccal epithelium among workers exposed to asbestos. Cytological examinations were performed to detect potential signs of cellular damage or early disease states related to asbestos exposure.

The results indicated that for workers with more than 20 years of exposure, the cellular alterations were similar to those observed in individuals without exposure (the control group). This was contrary to expectations since long-term asbestos exposure is typically associated with cellular damage. The authors interpreted these findings to suggest that over time, the bodies of these long-term exposed workers may have adapted to the presence of asbestos fibers. This implied, in the Authors' view, some form of physiological or cellular adjustment that resulted in reduced observable damage in the nasal and buccal epithelial cells. However, it should be noted that no evidence exists of a possible biological adaptation to carcinogens. Therefore, the most logical answer to the problem posed by these findings is simply that asbestos does not cause the cellular alterations that were searched for by these authors. For sure, asbestos is a known carcinogen, and the most diffused and accepted understanding is that the risk of disease increases with the duration and intensity of exposure, with some differences for mesothelioma.

3.3.3.4. Immunological Markers

Amanbekova et al. (2012) studied the cell and humoral immunity of 106 workers in the Kostanay Minerals JSC, examining the "shortened" panel of monoclonal antibodies (mAbs), immunoglobulins (IgA, IgM, IgG) and secretory immunoglobulin A (SIgA) through an ELISA test [24]. They reported decreased functional activity of the T-lymphocytes in a proportion of all immune cells, accompanied by a reduced number of CD3 cells in workers who had worked more than 20 years — 58.7±0.41% ($p<0.01$), compared to the control group (71,2±0,52%). A similar picture was reported in CD4 cells - 40.9±0.85% (control group 45,2±0,26), CD20 cells - 6.1±0.39% (control 12,7±1,09), and IgA 1.35±0.57 g/l (control group 2,85 ± 0,27 g/l), and an increase of IgG - 19,27±0,57 g/l (control group 11,27±0,14 g/l) of the employees who worked more than 20 years, respectively. Workers exposed to chrysotile asbestos over 20 years had decreased the mucous barrier of the nasal secretion in IgA - 0.16±0.03 g/l ($p<0.01$), compared with a control group (0.34±0.07 g/l).

In another study on 125 workers in the Kostanay Minerals JSC, Koigeldinova et al. (2022) found changes in the number of CD4+ T-cells [28]. In employees' occupational exposure of more than 15 years, the number of CD4+ T-cells was significantly lower than in those who had been working for less than 15 years. The levels of CD8+ T-cells were similar in these two examined groups. They concluded that most healthy workers with a longer occupational exposure to chrysotile have increased neutrophil phagocytic activity and a decreased total number of CD3+ T and CD4+ T cells but an increased number of CD8+ T-cells with a lower immunoregulating index of CD4+8+. Koigeldinova et al. (2015) also found that the workers of Kostanay Minerals JSC with longer occupational exposure to asbestos fibers have an increased activity of lipid peroxidation, which was more pronounced in the workers of the processing complex than the drivers and miners [21].

3.3.3.5. Biochemical and Cytological Changes

Ibraev et al. (2015) found that workers of Kostanay Minerals JSC showed destructive changes in the nasal mucosa and buccal epithelium cells. Notably, the alterations were primarily observed in the workers with less than 20 years of exposure, while in workers with more than 20 years of exposure, the pathological changes were not different, for incidence and entity, to those observed in the control group [26]. On the other hand, blood plasma analysis revealed elevated alveomucin 3EG5 levels ($p<0.05$), a marker of lung fibrosis, in workers with over 20 years of exposure compared to controls. They recommended measuring lipid peroxidation products and alveomucin 3EG5 levels in blood plasma as biomarkers of the initial stage of pneumoconiosis caused by chrysotile exposure.

3.3.3.6. Longitudinal Studies and Cellular Membrane Changes

A 7-year longitudinal study by Ibraev et al. (2016) revealed adaptive changes in cell membrane constituents, such as an increase in sphingomyelin (SM) and a decrease in phosphatidylcholine (PC) in workers with longer occupational exposure to asbestos-containing dust [20]. According to the authors ‘ opinion, these changes in the cell membrane, involving both the plastic and energy state of cells and the level of catecholamines, occurred due to adaptation to asbestos exposure at the workplace. Differences in the body's functional state were revealed in workers involved directly in the production for 4 to 5 years and in employees of the mining and transport department who had worked for between 5 and 6 years. For workers directly involved in the production, the authors regarded a working period of 5 years as a risk for developing occupational disease, while for employees of the mining and transport department, this risk began from 6 years.

3.3.3.7. Chromosomal and Genetic Findings

In a cytogenetic blood study of workers in chrysotile-asbestos production, Amanbekova et al. (2012) revealed structural disorders of chromosomes represented by aberrations of chromosome and chromatid types [25]. The authors observed higher rates of such induced chromosomal abnormalities in workers with more than 25 years of asbestos exposure. The frequency of cells with chromosomal aberrations in the peripheral blood lymphocytes of the leading group significantly exceeded the control values.

3.3.3.8. Morphological and Pathological Assessments

Ibraev et al. (2022) studied the morphological parameters and the dust content in lung tissue taken from autopsy material of 343 deceased individuals (including workers at Kostanay Minerals JSC and a control group composed of residents of Zhitikara who never worked at Kostanay Minerals JSC) [52]. They observed severe sclerosis and dust particles in the form of grains (pigments) of black color. These black dust particles were found in the lung sections of 33.3% of the workers of Kostanay Minerals and 44.6% of non-exposed residents of Zhitikara. Such particles, however, cannot be regarded as a specific consequence of asbestos exposure since they are different from asbestos bodies that appear as brown or dark yellow corpuscles at light microscopy. Moreover, the authors found more pronounced fibrotic changes, sometimes with the obliteration of alveoli, in the lung sections of Kostanay Minerals JSC workers compared to the controls, in which non-specific inflammation prevailed. The authors concluded that chrysotile occupational exposure does not increase the risk of developing pathologic changes in the lung tissue (RR-1.9 CI=0.68).

3.3.4. Epidemiological Studies

An epidemiological study by Altynbekov et al. (2018) investigated the prevalence of mesothelioma in Kazakhstan and examined the potential relationship between chrysotile asbestos exposure and the development of mesothelioma [33]. From 2012 to 2016, 17 mesothelioma cases were reported in Kazakhstan. The majority (95.7%) was represented by pleural mesothelioma, the remaining by peritoneal and pericardial mesothelioma. The age at diagnosis was between 40 and 70 years. Notably, in only 7.5% of diagnosed cases, there was a documented history of occupational asbestos exposure. The authors concluded from this data that there was no evident relationship between exposure to chrysotile asbestos and the development of mesothelioma. This was based on the low percentage of cases with documented occupational exposure. The study also reported some data regarding the geographical distribution of the cases, with 15.2% of cases coming from the Almaty region, 12.8% from the Kostanay region, and 10.5% from the Karaganda region. This is interesting as Almaty and Karaganda regions are not known for asbestos-producing facilities. While the study highlights the low incidence of occupational exposure in mesothelioma cases, it does not provide detailed environmental exposure data or a comprehensive description of asbestos-related work activities in Kazakhstan. It is essential to consider both occupational and environmental exposures when assessing the risks associated with asbestos because secondary or non-occupational exposures can also contribute to disease.

As already mentioned in the introduction, Kazakhstan has industries engaged in mining and producing asbestos-containing commodities. For instance, the Kostanay Minerals Enterprise is mentioned as the primary company involved in asbestos mining. Additionally, asbestos is used in various industries, including asbestos-cement goods manufacturing. Altynbekov et al.'s assertion that "no relationship between chrysotile asbestos exposure and mesothelioma" is controversial, given the widely recognized carcinogenicity of all forms of asbestos, including chrysotile. The International Agency for Research on Cancer (IARC) and other health authorities have concluded that all types of asbestos fibers are causally linked to mesothelioma and other asbestos-related diseases.

Only one study on pleural mesothelioma was conducted in Kyrgyzstan by Golovachev in 2008 [53]. He examined 12 patients with a newly diagnosed pleural mesothelioma at the National Centre of Oncology (NCO) in 2000-2005. Among these, seven were male (58.4%), and five female (41.6%); their average age was 44. The incidence rate of pleural mesothelioma in Kyrgyzstan was 0.14 per 100,000 men and 0.1 per 100,000 women in the same period. Histologically, malignant mesothelioma was confirmed in six patients (50%). In three patients (25%), the diagnosis remained histologically unverified due to their refusal to conduct diagnostic and therapeutic thoracoscopy. The rest (25%) were finally diagnosed with other types of malignant neoplasms. The patient's history showed occupational exposure to asbestos in five patients who had worked with asbestos insulation and asbestos-cement materials. The verification of the diagnosis was based on histological methods only, an immunohistochemical assay was never performed.

Comprehensive studies that account for all potential exposure routes, latency periods, and detailed work histories are essential for a more accurate assessment of the relationship between asbestos exposure and mesothelioma. The data should include occupational, environmental, and secondary exposures to give a complete picture of the asbestos-related health burden.

Even with the lack of studies in CA regarding ARDs, after an extensive search, we found some data on occupational diseases among workers only in the Bureau of National Statistics of the Republic of Kazakhstan database. According to them, "pneumoconiosis caused by asbestos and other minerals" (J61, ICD-10) was registered in 1 case in 2006, 10 cases in 2015, and 1 case in 2021 [37], with an age range predominantly from 30-45. Such data reflect the deficient reporting of ARDs. However, the findings of Chen et al. for Kazakhstan indicate a significant burden of asbestos-related diseases, with the country experiencing the highest age-standardized mortality rate (ASMR) and age-standardized DALY rate (ASDR) among the four countries studied: Russia, Brazil, China, Kazakhstan). Specifically, Kazakhstan's ASMR peaked at 4.89 per 100,000 population in 2015, while the ASDR reached a high of 123.75 per 100,000 in the same year. Between 1990 and 2019, Kazakhstan's ASMR and ASDR declined significantly, with a reduction of approximately -48.62% in ASMR and -54.06% in ASDR in men, represented by estimated annual percentage changes (EAPC) of -3.09 and -3.69, respectively. Despite these reductions, tracheal, bronchus, and lung (TBL) cancers remained the leading causes of asbestos-related mortality and DALYs, contributing to the sustained high disease burden [54]. At the same time, it is worth mentioning that the incidences of mesothelioma in CA countries, according to the WHO, are low compared to the European ones: 0.28/100,000 in Kazakhstan, 0.06/100,000 in Kyrgyzstan, 0.12/100,000 in Uzbekistan, 0.02/100,000 in Tajikistan, 0.15/100,000 in Turkmenistan compared to 1.7 for males and 0.4 for females in Europe [55].

4. Discussion

This review presents the available data about asbestos in CA countries, including epidemiology, exposure assessment, and experimental studies.

First, it is essential to note the need for more accurate data on the number of workers occupationally exposed to asbestos in Central Asia. For instance, it is known that Kazakhstan's Kostanay Minerals Enterprise, a significant asbestos producer in the region, employs approximately 2000 workers and produces substantial quantities of asbestos-containing materials. In contrast, countries like Kyrgyzstan, Uzbekistan, Tajikistan, and

Turkmenistan, while importing large amounts of asbestos (see Table 1) for manufacturing asbestos-containing products, must provide comprehensive data on their workforce engaged in these activities.

The absence of precise data concerning the number of workers engaged in asbestos processing presents significant constraints. One of the primary obstacles posed by this need for more information is the need for reliable denominators for statistical analysis and the difficulty in creating profiles of asbestos exposure among workers based on jobs, tasks, working time, etc., and determining ARD incidence among asbestos workers. Comprehensive studies that collect accurate occupational data, including the number of workers involved in asbestos-related industries, are imperative. Such efforts are essential for accurately assessing health risks associated with asbestos exposure, developing targeted public health strategies, improving worker safety standards, and advocating for the cessation of asbestos use in the region.

Even though incomplete, the existing data about occupational exposure to asbestos in Central Asia reveals alarming health outcomes reflective of outdated safety practices and inadequate regulatory frameworks. Studies at Kostanay Minerals JSC show high morbidity rates among workers, primarily due to respiratory diseases such as chronic bronchitis and pneumofibrosis [9]. Radiological findings by Ibraev et al. (2008) showed significant lung damage among workers with over 20 years of exposure, including perivascular and peribronchial pneumofibrosis [23]. These findings are evident from the elevated exposure levels at the workplace, which was reported by Amanbekova et al. (2014), showing that the daily dust concentrations were significantly higher than the maximum permissible concentration (MPC) in Kazakhstan [24]. This is concerning compared to Europe and other Western countries, where stringent occupational safety measures have been adopted. For example, the recent European directive (EU) 2023/2668 has established to modify the former OELV (8-hour time-weighted average (TWA) – PCM analysis) 0.1 ff/ml established by Directive 2009/148/EC, reducing it to 0.01 ff/ml (within 20 December 2029 – electron microscopy analysis) and then progressively to 0.002 ff/ml (from 21 December 2029 – electron microscopy analysis) [56]. In contrast, the average daily dust concentrations at Kostanay Minerals JSC, as reported by the studies mentioned above, were significantly higher, even considering the difficulties in comparison due to different analytical approaches, often exceeding national and international permissible limits [49, 56].

Other findings in CA literature were based on laboratory experiments performed on animals; the above-cited studies demonstrated the development of asbestos-related pneumofibrosis, which can lead to neoplasms. However, sufficient and relevant studies on cancers related to asbestos have just been published in CA. This can be explained by the need for well-established methods or equipment for applying the most internationally accepted approaches, sometimes due to insufficient financial support. Another issue that should be reported is that Occupational Health is not well-developed in CA countries. In Kyrgyzstan, for instance, only a few specialists in occupational diseases are active across the country, and the medical examination of workers is among the duties of general practitioners, who often lack the occupational health skills necessary to manage the health surveillance of workers [16]. It should be stressed, however, that awareness and consideration of the problem of asbestos hazards are generally evident in CA countries through the work of scientists in the corresponding fields.

Interestingly, countries with comprehensive asbestos regulations, such as those in the European Union, showed a decline in recognized cases of ARDs between 2013 and 2021. Specifically, there was a 26% decrease in the overall index of recognized occupational diseases, and in this frame, pneumoconiosis due to asbestos and other mineral fibers saw a 52% reduction.

Despite reductions over time, the findings by Chen et al. highlight that Kazakhstan continues to bear a high burden of asbestos-related diseases, mainly due to TBL cancers, which account for the majority of asbestos-related deaths and DALYs. Kazakhstan's peak ASMR and ASDR in 2015 and the highest values among the countries studied suggest that the population is still experiencing significant health impacts from asbestos exposure [54]. This indicates that while the EU has seen progress in controlling occupational diseases, CA countries face ongoing but under-recognized challenges, potentially due to differences in regulatory approaches, recognition of occupational diseases, and prevention measures taken [57, 58].

Even though all types of asbestos are known to be carcinogenic, the literature reports differences in the pathogenic potential according to asbestos type. However, there is no agreement about the lower neoplastic potential of chrysotile compared to amphiboles [59, 60]. In addition, most previous studies about fiber content in the lungs of asbestos workers non-occupationally exposed patients, and the general population has been conducted in Europe, the US, Canada, and Australia on subjects exposed to a mixture of chrysotile and amphiboles [61-63].

Instead, in CA, only chrysotile is mined and used, even though there is currently no sufficient evidence to prove that amphiboles do not contaminate the chrysotile ores here exploited. Chrysotile is considered less carcinogenic for the mesothelium than amphiboles; however, its association with mesothelioma has been described in some studies conducted in Italy and China [64, 65]. Recent research has significantly advanced our understanding of the health risks associated with asbestos exposure, particularly chrysotile, a topic of considerable debate. A comprehensive case-control study published in 2020 in the USA (investigating exposures that occurred from 1975 to 1980) suggests that both chrysotile alone and mixtures containing amphiboles pose significant risks of developing mesothelioma [66], contradicting the previously held view that chrysotile might be less hazardous than other forms of asbestos [59]. The study found that exposure to pure chrysotile was significantly associated with mesothelioma, even with a risk magnitude lower than amphiboles. The research underscores the heterogeneity in the risk of different fiber types and lengths, suggesting a nuanced approach to asbestos regulation and control strategies.

Despite the well-known hazardousness of chrysotile, in CA countries, there is a lack of epidemiological data on lung cancer. On the other hand, the incidence of mesothelioma, according to the available literature, appears to be as low as 0,28/100.000 in Kazakhstan and 0,06/100.000 in Kyrgyzstan; this unbelievably low incidence of mesothelioma (much lower compared to countries where asbestos has been banned for decades) might be due both to the type of asbestos used (maybe pure chrysotile) and perhaps to significant under-reporting of the diseases, owed, on one hand, to the lack of a sound diagnostic protocol and, on the other hand, to insufficient health surveillance of workers, which is recommended, in case of asbestos exposure, even after retirement. The protocol for mesothelioma diagnosis adopted in CA countries needs to be explained in detail in any of the consulted sources, and it does not include immunohistochemistry [67]. A suitable histopathologic protocol accompanied by an immunohistochemistry assessment is an essential tool in the differential diagnosis of this neoplasm, which could also be difficult for a very experienced pathologist.

Moreover, the scientific literature concerning asbestos exposure in CA needs to provide sufficient data to understand if workers and the general population are exposed to pure chrysotile substances or if amphibole contaminations occur. The available data described above have been produced using outdated and imprecise methods, lacking the accuracy of the widely shared updated recommendations. For instance, with a fiber-specific sampling method (and applicable, consistent exposure limits), industrial hygiene experts can fully understand the complex exposure picture for asbestos in CA. This means they cannot wholly and accurately evaluate the health risks of asbestos in the workplace. Asbestos has been recognized as different from other dust or fibers; thus, appropriate sampling and analysis techniques should be used to obtain data applicable to the industrial hygiene field. The microscopic method (e.g., ISO 14966-2019) has been used for many years to count and identify "respirable" asbestos fibers in fiber and dust samples collected on a filter. Moreover, recent analyses emphasize the importance of understanding the fiber type, length, and exposure duration when assessing health risks. Longer and thinner fibers are more persistent in lung tissue and, thus, more likely to cause mesothelioma and other lung diseases. This complexity is crucial for developing practical occupational health standards and protective measures.

Integrating the detailed exposure assessments from recent studies with regional insights can enhance our understanding of asbestos-related risks. Any safe exposure level is highly questionable and historical and current data should inform ongoing efforts to eliminate asbestos use and improve public health outcomes.

Our review delves into the impact of asbestos in Central Asia, shedding light on the widespread use and health consequences of heavy asbestos use in the region. Despite global banning policies, we show the ongoing production and use of asbestos, emphasizing the critical need for comprehensive exposure assessments and epidemiological data to guide public health measures.

Epidemiological and postmortem lung content studies are needed to address the above-summarized lack of data. Determining asbestos exposure, asbestos inhalation at the workplace and in both urban and rural environments, and asbestos persistence in the lungs, as well as the link between asbestos exposure (occupational and non-occupational) and neoplasms (malignant pleural mesothelioma, lung cancer, etc.), is an urgent and unmet public health issue in CA.

5. CONCLUSION

This is the first review of asbestos and its impact on the health of workers and the general population of CA countries, including also studies published in Russian. We emphasize that the arbitrary presentation of the results of reviewed studies and their notable incompleteness do not allow a clear understanding of the situation. The picture of asbestos-related issues in CA countries strongly needs to be improved. Several topics require attention: in the CA area, there are only a few studies on asbestos's impact on health, and almost no occupational and environmental exposure assessments are conducted adopting modern and internationally accepted methods. In particular, outdated techniques are often used to assess exposure in the cited studies. These methods are unsuitable for determining the composition of the revealed dust and distinguishing between asbestos and non-asbestos components. There is also a need for studies addressing the actual nature of asbestos mined in Kazakstan, as well as the link between mesothelioma risk and chrysotile exposure. CA might offer the opportunity to study the effects of exposures to chrysotile alone (if the absence of amphibole contamination were confirmed with suitable methods) and would help solve the still open problem regarding the capacity of chrysotile to pose a significant risk of pleural mesothelioma. Overall, a shortage of analytical foundations results in a substantial scarcity of inquiries and sizeable gaps in the few existing investigations. To fill this gap, more studies must be conducted according to updated and validated methods to address the currently open issues, investigating the amount of asbestos exposure and the impact of asbestos mining and use on public health. For sure, the situation in CA regarding asbestos represents a chance to conduct research, fill the existing knowledge gap, and improve the general knowledge regarding the toxicity of specific types of asbestos fibers.

FUNDING: This research received no external funding.

INSTITUTIONAL REVIEW BOARD STATEMENT: Not applicable.

INFORMED CONSENT STATEMENT: Not applicable.

DECLARATION OF INTEREST: ZK, KD, AS, SV, CS, OK, and EB declare no conflict of interest. CC acted as an expert for the court, the public prosecutor, and the defense in asbestos-related litigations.

DECLARATION ON THE USE OF AI: This paper was written entirely by ZK, KD, AS, SV, CS, OK, EB and CC without using artificial intelligence tools for drafting, generating, or rewriting content. Unless otherwise cited, all ideas, analyses, and conclusions are original and based on personal research.

SUPPLEMETARY MATERIAL: Figure S1. The inclusion and exclusion criteria for published articles on asbestos and asbestos-related diseases in CA Countries.

Table S1. Searching keywords and strings in international repositories.

Table S2. Summarized details of the selected articles.

References

1. Schulte PS, Trout D, Zumwalde RD. Asbestos fibers and other elongate mineral particles; state of the science and roadmap for research. NIOSH current intelligence bulletin 62; DHHS publication no. (NIOSH) 2011-159. Published online 2011. https://stacks.cdc.gov/view/cdc/5892 (Last Accessed October 2, 2023.)
2. Wachowski L, Domka L. Sources and effects of asbestos and other mineral fibres present in ambient air. *Pol J Environ Stud*. 2000;9(6):443-454.
3. IARC Working Group on the Evaluation of Carcinogenic Risks to Humans. Arsenic, metals, fibres, and dusts. *IARC Monogr Eval Carcinog Risks Hum*. 2012; 100(Pt C):11-465.
4. Mensi C, Riboldi L, De Matteis S, Bertazzi PA, Consonni D. Impact of an asbestos cement factory on mesothelioma incidence: global assessment of effects of occupational, familial, and environmental exposure. *Environ Int.* 2015;74:191-199. Doi: 10.1016/j.envint.2014.10.016
5. Zucali PA, Ceresoli GL, De Vincenzo F, et al. Advances in the biology of malignant pleural mesothelioma. *Cancer Treat Rev.* 2011;37(7):543-558. Doi: 10.1016/j.ctrv.2011.01.001
6. Kazan-Allen L. Asbestos and mesothelioma: worldwide trends. *Lung Cancer.* 2005;49 Suppl 1:S3-8. Doi: 10.1016/j.lungcan.2005.03.002
7. Marinaccio A, Binazzi A, Cauzillo G, et al. Analysis of latency time and its determinants in asbestos-related malignant mesothelioma cases of the Italian register. *Eur J Cancer.* 2007;43(18):2722-2728. Doi:10.1016/j.ejca.2007.09.018
8. Darcey DJ, Feltner C. Occupational and environmental exposure to asbestos. In: Oury TD, Sporn TA, Roggli VL, eds. Pathology of Asbestos-Associated Diseases. *Springer Berlin Heidelberg*. 2014:11-24. Doi: 10.1007/978-3-642-41193-9_2
9. Furuya S, Chimed-Ochir O, Takahashi K, David A, Takala J. Global Asbestos Disaster. *Int J Environ Res Public Health*. 2018;15(5). Doi: 10.3390/ijerph15051000
10. International Labour Organisation. C162 - Asbestos Convention, 1986 (No. 162). 1986. Accessed November 18, 2022. https://www.ilo.org/dyn/normlex/en/f?p=NORMLEXPUB:12100:0::NO::P12100_ILO_CODE:C162
11. International Labour Organisation. Safety in the Use of Asbestos: An ILO Code of Practice.; Geneva, ILO, 1984. https://www.ilo.org/sites/default/files/wcmsp5/groups/public/%40ed_protect/%40protrav/%40safework/documents/normativeinstrument/wcms_107843.pdf (Last Accessed October 31, 2024)
12. Laurie Kazan-Allen. Current Asbestos Bans. 2022. (Last Accessed November 18, 2022). http://ibasecretariat.org/alpha_ban_list.php
13. eLIBRARY.RU – electronic library of scientific publications. Accessed October 7, 2023. https://www.elibrary.ru/defaultx.asp (Available in Russian)
14. Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *Syst Rev.* 2021;10(1):89. Doi: 10.1186/s13643-021-01626-4
15. Page MJ, McKenzie JE, Bossuyt PM, et al. Updating guidance for reporting systematic reviews: development of the PRISMA 2020 statement. *J Clin Epidemiol*. 2021;134:103-112. Doi: 10.1016/j.jclinepi.2021.02.003
16. Scientific Production Association "Preventive Medicine. Hygiene Assessment of the Working Conditions of Workers Engaged in the Production of Asbestos-Cement Products. Ministry of Health of the Kyrgyz Republic; 2020:68. (Available in Russian)
17. Trade Map – Trade statistics for international business development. Accessed December 26, 2022. https://www.trademap.org/Index.aspx
18. Ibraev SA, Otarov Ez, Zharylkasyn Z, Koigeldinova Sh S, Kulov DB, Kalishev MG. The possibility of predicting the pathology of the lungs in terms of the allowable work experience with chrysotile. *Med Tr Prom Ekol*. 2015;(3):8-11. (Available in Russian)
19. Korotenko VA, Kirilenko AV, Kurokhtin AV, Neronova TI, Vashneva NS, Yakovlev MV. Asbestos: the practice of application in Kyrgyzstan, problems and recommendations. *Survey study*. Published online 2011. (Available in Russian)
20. Ibraev SA, Pankin YN, Koygeldinova SS, et al. [Longitudinal study of differences between functional state of the body in workers at the chrysotile asbestos plant]. *Gig Sanit*. 2016;95(10):961-965. (Available in Russian)
21. Koigeldinova SS, Ibraev SA, Kasymova AK. State of lipid peroxidation in workers engaged into chrysotile-asbestos production. *Meditsina truda i promyshlennaia ekologiia*. 2015;(3):5-8. (Available in Russian)
22. Baselyuk LT, Bekpan AZ. Cytological analysis of smears of the nasal mucosa and buccal epithelium of the cheeks in workers of the chrysotile-asbestos production of JSC Kostanay Minerals. *Toxicological Bulletin*. 2011; (2 (107)):20-23. (Available in Russian)
23. Ibraev SA, Kazimirova OV, Eshmagambstova JA, Sydyrmanova TV, Kasymova AK. Clinical and functional characteristics of the state of the bronchopulmonary system under the influence of chrysotile-asbestos dust. *Russ J Occup Heralth Indust. Ecol*. 2008;(2):30-33. (Available in Russian)
24. Amanbekova AU, Azhimetova GN, Gazizov OM, Bekpan AZ. Characteristics of the immune system of the organism of workers in chrysotile-asbestos production. Bulletin of Karaganda University. Published online 2012:61.
25. Amanbekova AU, Ibrayeva LK, Azhimetova GN, Zhumabekova GS. Identification of induced

mutagenesis by method of accounting of chromosomal aberrations at the workers of chrysotile asbestos production. *Bulletin of Karaganda University*. 2012;66(2): 12-16.

26. Ibraev SA, Zharylkasyn ZZ, Otarov EZ, et al. Biochemical indicators in interstitial pneumofibrosis in workers with chrysotile. *Bulletin of the Ural Medical Academic Science*. 2015;(2):53-55. (Available in Russian)
27. Kurkin AV, Abaevna DZ, Khabibullaevna RD. Cytological study of buccal epithelium with different work experience in chrysotile-asbestos production. *Russ. J Occup Heralth Indust Eco.* 2015;(3):16-18. (Available in Russian)
28. Koigeldinova S, Alexeyev A, Zharylkassyn Z, et al. Immune Status of Workers with Professional Risk of Being Affected by Chrysotile Asbestos in Kazakhstan. *Int J Environ Res Public Health.* 2022;19(21):14603.
29. Amanbekova AU, Sakiev KZ, Ibraeva LK, Otarbaeva MB. [Main results of research concerning asbestos-related diseases in Kazakhstan Republic]. *Med Tr Prom Ekol.* 2014;(8):13-18. (Available in Russian)
30. Koigeldinova SS, Ibraev SA, Bazelyuk LT, Kasymova AK, Talaspayeva AE. Phagocytosis of alveolar macrophages in experimental animals exposed to chrysotile-asbestos dust. *Hygiene and Sanitation*. 2021;100(1):73-76. (Available in Russian)
31. Ainagulova G, Bulgakova O, Ilderbayev O, Manekenova K, Tatayeva R, Bersimbaev R. Molecular and immunological changes in blood of rats exposed to various doses of asbestos dust. *Cytokine*. 2022;159:156016. Doi: 10.1016/j.cyto.2022.156016
32. Akhmadaliev MA, Askarov IR, Turdiboev IHU. Mineral-basalt fibers instead of carcinogenic asbestos-containing composite materials. *Universum: engineering sciences*. 2021;(8-2 (89)):17-20. (Available in Russian)
33. Altynbekov MB, Sembaev Z, Salimbaeva BM. Regional assessment of mesothelioma incidence in the Republic of Kazakhstan. In: State budgetary educational institution of higher professional education Tver State Medical Academy of the Ministry of Health of the Russian Federation; 2018:58-61. (Available in Russian)
34. Ibraev SA, Otarov EZ, Zharylkasyn LJ, Koigeldinova S. Controlled use of chrysotile through occupational risk development. *Medicine of Kyrgyzstan*. 2014;(4):88-90. (Available in Russian)
35. Ibraev S, Alekberov M, Zharylkassyn Z, Otarov E, Tilemisov M. [analysis of morbidity with temporary disability of workers in the ore beneficiation on chrysotile production]. *Georgian Med News*. 2018;(283): 104-108. (Available in Russian)
36. Allen, Lucy P, Baez, Jorge, Stern, Mary Elizabeth C & George, Frank. (2017). Asbestos: economic assessment of bans and declining production and consumption. World Health Organization. Regional Office for Europe. https://iris.who.int/handle/10665/344114
37. Agency for Strategic planning, reforms of the Republic of Kazakhstan Bureau of National Statistics. Agency for Strategic planning and reforms of the Republic of Kazakhstan Bureau of National statistics. Published online 2022. (Available in Russian)
38. Kostanay Minerals JSC. Accessed November 18, 2022. https://km.kz/en/%D0%B3%D0%BB%D0%B0%D0%B2%D0%BD%D0%B0%D1%8F-english/
39. National Statistical Committee of the Kyrgyz Republic. The Population of Kyrgyzstan. Book II. Census, 2022. National Statistical Committee; 2023. (Available in Russian)
40. Kant Pipe - Slate Enterprise. About the company. Accessed November 18, 2022. https://kantslate.kg/en/about
41. About company | Industrial complex "Uralasbest." Accessed October 19, 2023. https://www.uralasbest.ru/en/about-company
42. Kant Kurulush. Kant Kurulush. Accessed February 10, 2023. http://www.kurulush.kg/. (Available in Russian)
43. Agency on statistics under the President of the Republic of Uzbekistan. Permanent population. Accessed February 13, 2023. https://stat.uz/en/
44. The Observatory of Economic Complexity. Bilateral-product. Asbestos. Accessed February 13, 2023. https://oec.world/en/profile/bilateral-product/asbestos/reporter/
45. The Association of building materials industry enterprises of Uzbekistan. Database of building materials manufacturers. Asbestos-cement products.
46. Agency on statistics under the President of the Republic of Tajikistan. Population. Accessed February 13, 2023. https://www.stat.tj/en. (Available in Russian)
47. The World Bank Group. Country. Turkmenistan. Accessed February 13, 2023. https://data.worldbank.org/
48. Ibraev SA, Otarov EJ, Zeynidenov AK. Some data on the physicochemical properties of the surface of chrysotile-asbestos fiber. *Bulletin of Karaganda University.* 2011;2(62):3-7. (Available in Russian)
49. Ministry of Health of the Republic of Kazakhstan R of K. On Approval of Hygienic Standards for Atmospheric Air in Urban and Rural Settlements, in the Territories of Industrial Organizations; 2022. (Available in Russian)
50. Government of the Kyrgyz Republic. Hygienic Standards "Maximum Permissible Concentrations of Harmful Substances in the Air of the Working Zone."; 2016. Accessed February 1, 2023. http://cbd.minjust.gov.kg/act/view/ky-kg/11958?cl=ky-kg. (Available in Russian)
51. World Health Organization. Determination of Airborne Fibre Number Concentrations: A Recommended Method, by Phase Contrast Optical Microscopy (Membrane Filter Method). World Health Organization; 1997:53.
52. Ibraev SA, Zharylkasyn ZhZh, Alekseev AV, Sokharev EYu. Lung tissue and the content of chrysotile dust in persons living in Zhitikara, in the section. In: NAO "MEDICAL UNIVERSITY OF KARAGANDY".; 2022:85-87. (Available in Russian)

53. Golovachev SV. Some epidemiological aspects of malignant pleural mesothelioma. *Vestnik KRSU.* 2008;8(4):93. (Available in Russian)
54. Chen J, Wang C, Zhang J, et al. A comparative study of the disease burden attributable to asbestos in Brazil, China, Kazakhstan, and Russia between 1990 and 2019. *BMC Public Health.* 2022;22(1):2012. Published 2022 Nov 3. Doi: 10.1186/s12889-022-14437-6
55. Ferlay J, Lam F, Colombet M, et al. EM. Global Cancer Observatory: Cancer Today. 2020. [Last Accessed January 27, 2023]. https://gco.iarc.fr/today
56. Directive (EU) 2023/2668 amending Directive 2009/148/EC on the protection of workers from the risks related to exposure to asbestos at work – European Sources Online. Accessed June 22, 2024. https://www.europeansources.info/record/proposal-for-a-directive-amending-directive-2009-148-ec-on-the-protection-of-workers-from-the-risks-related-to-exposure-to-asbestos-at-work/
57. Occupational diseases statistics - Statistics Explained. Accessed June 22, 2024. https://ec.europa.eu/eurostat/statisticsexplained/index.php?title=Occupational_diseases_statistics&oldid=623809
58. Eurogip. EUROPEAN FORUM of the Insurance against Accidents at Work and Occupational Diseases Enquiry Report. Published online 2006. Accessed June 22, 2024. www.eurogip.fr
59. Gibbs GW, Berry G. Mesothelioma and asbestos. *Regul Toxicol Pharmacol.* 2008;52(1 Suppl):S223-31. Doi: 10.1016/j.yrtph.2007.10.003
60. Smith AH, Wright CC. Chrysotile asbestos is the main cause of pleural mesothelioma. *Am J Ind Med.* 1996; 30(3):252-266. doi:10.1002/(SICI)1097-0274(199609)30:3<252::AID-AJIM2>3.0.CO;2-0
61. Visonà SD, Capella S, Bodini S, et al. Inorganic Fiber Lung Burden in Subjects with Occupational and/or Anthropogenic Environmental Asbestos Exposure in Broni (Pavia, Northern Italy): An SEM-EDS Study on Autoptic Samples. *Int J Environ Res Public Health.* 2021;18(4). Doi: 10.3390/ijerph18042053
62. Casali M, Carugno M, Cattaneo A, et al. Asbestos Lung Burden in Necroscopic Samples from the General Population of Milan, Italy. *Ann Occup Hyg.* 2015;59(7):909-921. Doi: 10.1093/annhyg/mev028
63. Barbieri PG, Somigliana A, Chen Y, Consonni D, Vignola R, Finotto L. Lung Asbestos Fibre Burden and Pleural Mesothelioma in Women with Non-occupational Exposure. *Ann Work Expo Health.* 2020;64(3):297-310. Doi: 10.1093/annweh/wxaa009
64. Mirabelli D, Calisti R, Barone-Adesi F, Fornero E, Merletti F, Magnani C. Excess of mesotheliomas after exposure to chrysotile in Balangero, Italy. *Occup Environ Med.* 2008;65(12):815-819. Doi: 10.1136/oem.2007.037689
65. Lin S, Wang X, Yu ITS, et al. Cause-specific mortality in relation to chrysotile-asbestos exposure in a Chinese cohort. J Thorac Oncol. 2012;7(7):1109-1114. Doi: 10.1097/JTO.0b013e3182519a60
66. Wong JYY, Rice C, Blair A, Silverman DT. Mesothelioma risk among those exposed to chrysotile asbestos only and mixtures that include amphibole: a case-control study in the USA, 1975-1980. *Occup Environ Med.* Published online October 21, 2020. Doi: 10.1136/oemed-2020-106665
67. Republic of Kazakhstan. Pleural mesothelioma > Clinical protocols of the Ministry of Health of the Republic of Kazakhstan - 2017 (Kazakhstan). MedElement. November 10, 2017. Accessed November 13, 2023. https://diseases.medelement.com/disease/%D0%BC%D0%B5%D0%B7%D0%BE%D1%82%D0%B5%D0%BB%D0%B8%D0%BE%D0%BC%D0%B0-%D0%BF%D0%BB%D0%B5%D0%B2%D1%80%D1%8B-2017/15485