EXPERIMENTAL EVALUATION OF ASBESTOS FIBER DISPERSION FROM DEGRADED ASBESTOS-CEMENT MATERIALS UNDER SIMULATED HANDLING SCENARIOS

C. LUCA, National University of Science and Technology POLITEHNICA Bucharest, Bucharest, Romania, luca.ctin@yahoo.com
M.G. BOBOCEA, National University of Science and Technology POLITEHNICA Bucharest, Bucharest, Romania
N. ADOCHITEI (PRESURA), National University of Science and Technology POLITEHNICA Bucharest, Bucharest, Romania
C. BORDA, National University of Science and Technology POLITEHNICA Bucharest, Bucharest, Romania
C. RADU, National University of Science and Technology POLITEHNICA Bucharest, Bucharest, Romania

Abstract. *The presence of asbestos-containing materials in the existing building stock continues to pose a major occupational health risk, particularly in the context of renovation, maintenance, and demolition activities. Although the use of asbestos has been banned across the European Union, numerous construction elements made of asbestos cement remain in service, and their degradation can promote the release of respirable fibers into the air. The aim of this study is the experimental evaluation of asbestos fiber dispersion as a function of material condition and the type of mechanical stress applied, under controlled laboratory conditions.*

The methodology involved testing asbestos-cement samples classified according to their degree of degradation (intact and degraded) in three simulated scenarios: static handling, dry manual cutting, and mechanical impact. Airborne fiber concentrations were determined by phase-contrast optical microscopy (PCM), in accordance with the NIOSH 7400 method, used as an index method, while identification and morphological characterization were carried out by electron microscopy (SEM/EDX and TEM), in compliance with ISO 14966 and ISO 10312 standards.

The results highlight a significant increase in fiber dispersion with increasing mechanical stress, with the highest values associated with cutting and impact scenarios. Degraded samples consistently exhibited higher emission levels than intact ones, confirming the critical role of cement matrix degradation in fiber release. Granulometric analysis indicated a predominance of respirable fibers, with dimensions favorable for penetration into the lower respiratory tract. In addition, the temporal dynamics of dispersion revealed the existence of a critical interval immediately after the initiation of mechanical stress, characterized by peak concentrations.

Keywords: asbestos cement; airborne fibers; occupational exposure; material degradation; particle dispersion.

1. INTRODUCTION

Asbestos is one of the most significant occupational carcinogenic agents, being associated with serious diseases such as mesothelioma, lung cancer, and asbestosis. Although its use has been banned in the European Union, asbestos-containing materials are still present in many buildings constructed before the 2000s, particularly in the form of asbestos-cement sheets, insulation materials, or sealing products.

In the current context of energy retrofitting and rehabilitation of old buildings, the risk of exposure to asbestos fibers remains high, especially in the case of uncontrolled interventions.

Recent studies and European regulations emphasize the need for a drastic reduction in occupational exposure, including through the lowering of the occupational exposure limit to 0.01 fibers/cm³, a value adopted at the European Union level.

An aspect that has been insufficiently investigated in practice is the influence of material degradation on fiber release. Asbestos-cement materials are initially considered “non-friable”; however, aging, carbonation, and erosion processes can reduce the cohesion of the cement matrix and transform these materials into active sources of contamination during handling.

The present study aims to experimentally analyze how the physical condition of the material and the type of mechanical stress affect the dispersion of asbestos fibers into the air.

2. LITERATURE REVIEW

Literature Review

Exposure to asbestos remains a major occupational and environmental health issue, even in countries where its use has been banned. The persistence of asbestos-containing materials in the existing building stock contributes to ongoing exposure, particularly in the context of renovation and demolition works [9]. Asbestos is a group of fibrous silicate minerals, among which chrysotile represents the predominantly used form in construction materials, including asbestos cement [11].

Numerous studies have demonstrated that the degradation of asbestos-containing materials leads to the release of fibers into the air, even in the absence of direct industrial sources. For example, a recent systematic analysis showed that asbestos-based building materials exposed to climatic factors can generate fiber emissions into the ambient environment, even at apparently low but health-relevant levels [5]. Erosion processes, acid rain, and atmospheric pollution contribute to matrix degradation and increased fiber mobility [5].

In the occupational environment, the construction sector is considered one of the most exposed to asbestos, particularly during rehabilitation and demolition activities [1]. Cumulative exposure to asbestos fibers is associated with an increased risk of developing occupational diseases, including asbestosis and lung cancer [1]. Epidemiological studies have shown that workers involved in handling asbestos-containing materials have a higher incidence of severe respiratory diseases [3].

In addition to occupational exposure, there is growing interest in assessing background exposure in the ambient environment. Recent studies indicate that in countries where asbestos is banned, the main sources of exposure are existing materials in buildings and infrastructure, rather than industrial activities [5]. This highlights the importance of evaluating material condition and degradation processes.

Regarding methods for asbestos fiber determination, the scientific literature emphasizes the combined use of optical and electron microscopy. Phase Contrast Microscopy (PCM) is widely used for determining total fiber concentration and is considered an index method [6]. However, PCM does not allow for specific identification of fiber types, which is why it is complemented by electron microscopy techniques such as SEM and TEM [6].

Recent studies conducted within European occupational safety research networks have highlighted significant differences between analytical methods (PCM, SEM, TEM), underlining the need for harmonization to ensure accurate exposure assessment [6]. Direct comparison of results obtained by different methods has demonstrated that dimensional evaluation of fibers is essential for estimating actual risk [6].

Furthermore, experimental research has shown that mechanical activities applied to asbestos-containing materials, such as cutting, drilling, or fragmentation, lead to significant increases in airborne fiber concentrations [0]. These findings are consistent with observations that initially non-friable materials can become major sources of contamination following degradation and handling [5].

Another important aspect highlighted in the literature is the influence of fiber size on toxicity. Thin and elongated fibers have an increased capacity to penetrate the respiratory system and are associated with more severe carcinogenic effects [9]. Moreover, the morphological characteristics of chrysotile, including its flexible and fibrillar structure, contribute to easy dispersion in air and inhalation [11].

Overall, the scientific literature consistently indicates that asbestos-related risk is determined not only by the presence of the material but also by its physical condition, environmental conditions, and the type of intervention applied. There is a consensus on the need to develop standardized assessment methods and to implement strict control measures in both occupational and environmental contexts [5], [6].

3. METHODOLOGY

The evaluation of fiber dispersion was carried out through a dynamic experiment. The objective of the experiment was to demonstrate the amount of fibers released when the material is handled. To achieve this, a controlled experimental setup was required.

3.1. Analyzed samples

The samples were collected from construction elements (roofs and façade panels) originating from old industrial and residential buildings. They were selected based on:

- estimated age (over 20–30 years);
- degree of visible degradation (intact vs. degraded);
- integrity of the cement matrix.

Each sample was characterized through preliminary macroscopic and microscopic observations (fig.1).

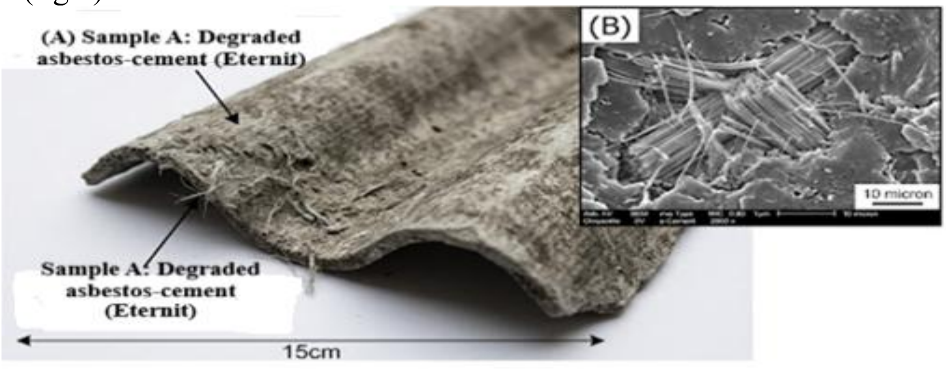

Figure 1. Characterization of degraded asbestos-cement samples

Macro Photo (A): Degraded asbestos-cement sheet, collected from an industrial roof. Surface erosion and exposed fibers can be observed.

Micro Photo (B – SEM): Scanning Electron Microscopy image of the same sample, showing bundles of chrysotile fibers (white asbestos) embedded in the cement matrix. This confirms the identity of the material.

3.2. Configuration of the experimental laboratory setup

The experiments were carried out in a controlled enclosure designed to limit external contamination and ensure reproducibility. The experimental system included an isolated test chamber, a sample-handling system, air-sampling pumps equipped with MCE filters, a real-time particle monitor, personal protective equipment, and HEPA filtration systems (fig.2).

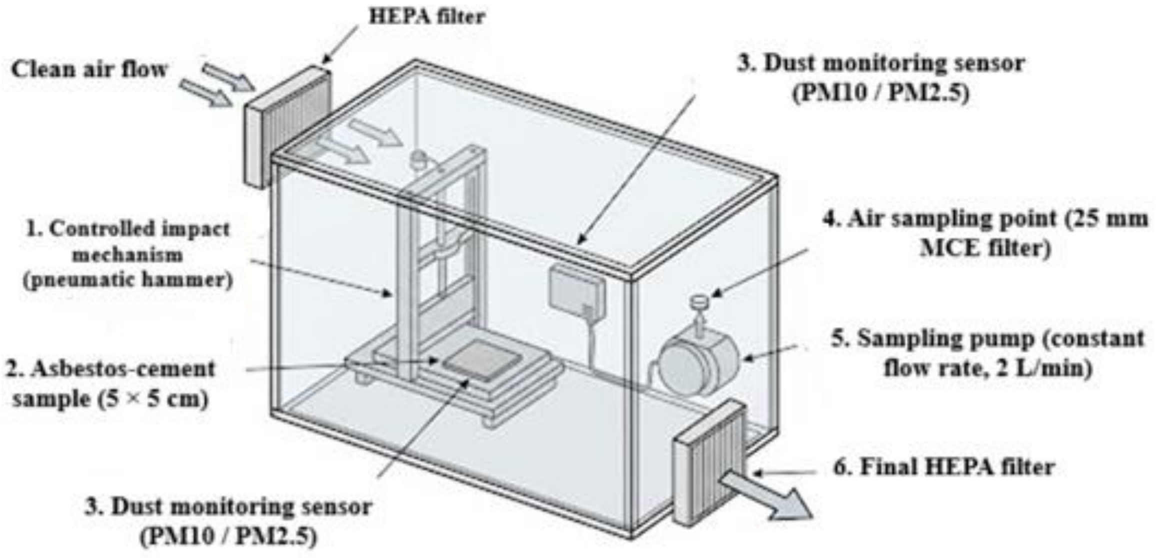

Figure 2. Schematic of the experimental setup for simulating fiber dispersion

3.3. Experimental scenarios

Three testing scenarios were defined:

- S1 – static handling: manual movement of samples; simulation of unloading and stacking asbestos cement sheets. The samples were moved across a rough surface at a constant speed of 0.5 m/s.
- S2 – dry manual cutting: sectioning without wetting; use of a hand tool to cut the material without water supply (dry cutting), representing the most common scenario of non compliance with safety regulations.
- S3 – mechanical impact: simulation of fragmentation by impact; simulation of falling from height or striking with blunt objects, using a pneumatic striker with an impact energy of 15 J.

3.4. Fiber determination

Fiber concentrations were determined by the PCM method according to NIOSH 7400, used as an index method for fiber counting.

For specific asbestos identification and dimensional analysis, the following techniques were used:

- Scanning Electron Microscopy (SEM/EDX) – in accordance with ISO 14966;
- Transmission Electron Microscopy (TEM) – in accordance with ISO 10312 and NIOSH 7402.

This combined approach allows differentiation between total fibers and asbestos fibers.

3.5. Data analysis

The results were analyzed statistically using descriptive indicators and correlation coefficients to evaluate the relationship between material condition and fiber dispersion.

4. RESULTS AND DISCUSSION

The obtained results show a progressive increase in airborne fiber concentration with increasing mechanical stress applied to the material (Table 1).

In Scenario S1, static handling of intact samples generated low mean values of approximately 0.005 f/cm³, below the reference value currently used in the European context (0.01 f/cm³).

In contrast, degraded samples reached a mean of 0.013 f/cm³, suggesting that even simple handling of material affected by aging and erosion can already exceed the current comparison threshold.

In Scenario S2, corresponding to dry manual cutting, a sharp increase in fiber concentration was observed, with simulated mean values of 0.067 f/cm³ for intact samples and 0.166 f/cm³ for degraded samples. These values indicate a high exposure potential under uncontrolled working conditions.

Scenario S3, representing mechanical impact, generated the highest dispersion levels, with mean values of 0.126 f/cm³ for intact samples and 0.307 f/cm³ for degraded samples. This behavior confirms that mechanical fragmentation of old materials represents the most critical scenario from an occupational risk perspective.

Table 1. Fiber concentration by experimental scenario (fibre/cm³)

Scenario	Sample	Replicate 1	Replicate 2	Replicate 3	Averange/Mean	SD
S1 – static handling	P-I	0.004	0.005	0.006	0.005	0.001
S1 – static handling	P-D	0.011	0.013	0.014	0.013	0.002
S2 – dry cutting	P-I	0.062	0.071	0.068	0.067	0.005
S2 – dry cutting	P-D	0.154	0.168	0.176	0.166	0.011
S3 – mechanical impact	P-I	0.118	0.126	0.134	0.126	0.008
S3 – mechanical impact	P-D	0.284	0.311	0.327	0.307	0.022

4.1 Temporal dynamics of fiber dispersion

Analysis of airborne fiber concentration over time highlights dynamic behavior typical of fine particle release and transport processes induced by mechanical stress (Table 2).

In all investigated scenarios, a concentration peak appears within 60–120 seconds after initiation of the action, followed by a progressive decrease, attributable to physical mechanisms of dispersion, dilution, and sedimentation.

Tabel 2. Temporal dynamics of fiber dispersion (fibre/cm³)

S1 – Static handling

Time (s)	P-I	P-D
0	0.000	0.000
30	0.003	0.008
60	0.005	0.011
120	0.006	0.013
180	0.005	0.012
300	0.004	0.010

S2 – Dry cutting

Time (s)	P-I	P-D
0	0.000	0.000
30	0.028	0.074
60	0.051	0.126
120	0.073	0.181
180	0.069	0.171
300	0.054	0.139
600	0.025	0.071

S3 – Mechanical impact

Time (s)	P-I	P-D
0	0.000	0.000
30	0.086	0.201
60	0.119	0.281
120	0.138	0.336
180	0.131	0.318
300	0.094	0.244
600	0.041	0.109

In S1, variations are limited and relatively stable over time, indicating that in the absence of significant mechanical stress, fiber release is confined to already exposed material surfaces. The slight increase during the first minutes may be attributed to detachment of weakly adhered surface particles without matrix fragmentation.

Conversely, S2 and S3 show rapid and pronounced increases in fiber concentration, peaking within 60–120 seconds. Mechanical impact exhibits the most pronounced peak, suggesting instantaneous and massive fiber release typical of brittle fracture in degraded materials.

After peak values are reached, all curves show a downward trend, faster for intact samples and slower for degraded ones. This decline is explained by gravitational sedimentation of larger particles and concentration dilution due to redistribution in the available air volume. Higher residual concentrations in degraded samples indicate a greater proportion of fine particles that remain suspended for longer periods.

This behavior is occupationally relevant, highlighting a critical exposure interval immediately after work initiation, emphasizing the need for early implementation of control measures.

4.2 Granulometry / respirable fraction

The analysis of fiber size distribution highlights a clear trend toward an increase in the respirable fraction with increasing mechanical stress, as well as a significant influence of the material's degradation state.

Across all analyzed scenarios, it can be observed that the proportion of fine fibers (with diameters below 0.5 µm) and those classified within the respirable range progressively increases from Scenario S1 (static handling) to Scenario S3 (mechanical impact).

Tabel 3. Dimensional distribution of identified fibers (% of total observed fibers)

Dimensional category	Indicative criterion	**S1 P-I**	**S1 P-D**	**S2 P-I**	**S2 P-D**	**S3 P-I**	**S3 P-D**
Fine respirable fibers	L > 5 µm; D < 0.5 µm	28	34	41	49	46	54
Medium respirable fibers	L > 5 µm; D = 0.5–1.0 µm	22	25	29	31	27	28
Elongated fragments	L > 5 µm; D = 1.0–3.0 µm	18	17	15	12	12	10
Non-respirable fragments	D > 3.0 µm sau L < 5 µm	32	24	15	8	15	8

In the case of static handling, the distribution is relatively balanced, with a substantial share of non-respirable fragments, particularly for intact samples. This suggests that, in the absence of significant mechanical stress, the material predominantly releases larger particles resulting from superficial detachment processes. Nevertheless, even under these conditions, degraded materials exhibit a higher proportion of fine fibers compared to intact ones, indicating that aging processes reduce matrix cohesion and promote the release of smaller particles.

The transition to Scenario S2 (dry cutting) leads to a marked modification of the distribution, characterized by an increase in the respirable fiber fraction and a reduction in the proportion of larger fragments. This phenomenon is associated with abrasion processes, which generate fibers through progressive detachment from the cement matrix. In degraded samples, this trend is amplified, confirming the critical role of the material's physical condition in determining exposure risk.

Scenario S3 (mechanical impact) shows the most pronounced shift of the distribution toward the fine particle range. The proportion of fine respirable fibers becomes dominant, particularly for degraded materials, while the fraction of non-respirable fragments decreases significantly. This behavior can be explained by brittle fracture mechanisms, which lead to the generation of a large number of thin, elongated fibers capable of remaining suspended for extended periods.

From a toxicological perspective, this evolution is particularly relevant, as fine fibers with high aspect ratios have the greatest capacity for penetration into the alveolar region. Thus, not only the total fiber concentration is important, but also the dimensional distribution, which directly influences pulmonary retention potential and, consequently, the risk of long-term adverse effects. The results support the conclusion that degraded materials subjected to mechanical stress represent a major source of respirable particles and must be treated as a critical factor in occupational risk assessment.

4.3 Correlation between material age and dispersion

The analysis of the relationship between the estimated age of asbestos-cement materials and the average concentration of fibers released under the dry-cutting scenario (S2) reveals a clear trend of increasing dispersion as degradation processes progress over time. The values presented in the table indicate an almost linear increase in fiber concentration, from relatively low levels associated with more recent materials (12–18 years) to significantly higher values observed for materials aged over 35–40 years.

Tabel 4. Estimated material age and average fiber concentration in Scenario S2

Sample	Estimated age (years)	Mean S2 concentration (f/cm³)
P1	12	0.041
P2	18	0.052
P3	24	0.061
P4	27	0.074
P5	31	0.096
P6	34	0.118
P7	38	0.143
P8	42	0.167

This trend suggests the existence of a strong positive correlation between material age and its ability to release fibers under mechanical stress.

From a physicochemical perspective, this behavior can be explained by cumulative processes of carbonation, micro-cracking, and erosion of the cement matrix, which progressively reduce structural cohesion and the capacity to retain asbestos fibers.

As a result, fibers become less firmly anchored within the matrix and are more readily released during cutting operations.

It can be observed that for samples with an estimated age of less than approximately 20 years, the increase in fiber concentration is moderate, indicating a relatively stable material structure.

Beyond an age threshold of approximately 30 years, however, the slope of the curve becomes steeper, suggesting accelerated degradation and a significant loss of matrix integrity. This behavior can be associated with the cumulative effects of freeze–thaw cycles, temperature variations, and prolonged exposure to atmospheric agents.

From an occupational perspective, this correlation has important implications, as it indicates that material age may be used as an indirect indicator of exposure risk in the absence of detailed laboratory analyses. Nevertheless, it is important to emphasize that age should not be considered as a sole criterion, but rather correlated with visible degradation status and the type of intervention performed.

The results support the conclusion that older materials, particularly those exposed for extended periods to environmental factors, exhibit an increased potential for generating respirable fibers during mechanical processing activities. Consequently, interventions involving such materials require stricter control measures and a thorough pre-assessment of exposure risk.

5. CONCLUSIONS

The primary objective of the experimental study presented was to evaluate the behavior of asbestos-cement materials under simulated handling and mechanical stress conditions, with particular emphasis on the influence of material degradation on airborne fiber dispersion.

The obtained results demonstrate that the risk of exposure to asbestos fibers is not determined solely by the type of material, but primarily by its physical condition and the nature of the intervention applied.

First, the comparative analysis of the three experimental scenarios (static handling, dry cutting, and mechanical impact) demonstrated the existence of a direct relationship between the intensity of mechanical stress and the level of fiber dispersion. Static handling generates relatively low emissions, particularly for intact materials; however, even in this scenario, exceedances of current reference values may occur when degraded samples are involved. In contrast, scenarios involving fragmentation or abrasion processes lead to significant increases in fiber concentration, confirming the critical nature of these operations from an occupational health and safety perspective.

A second important finding concerns the major influence of material degradation on its behavior. Degraded samples exhibited higher dispersion levels in all scenarios compared to intact ones. This phenomenon is explained by physicochemical aging processes of the cement matrix, which result in loss of cohesion and facilitate asbestos fiber release. In this context, the study confirms that materials initially classified as non-friable can become significant sources of contamination following degradation and mechanical intervention.

The analysis of temporal dispersion dynamics revealed the existence of a critical interval immediately after the initiation of work activities, characterized by peak fiber concentrations. This dispersion peak, observed within the first 60–120 seconds, is followed by a gradual decline driven by sedimentation and dilution processes. From a practical standpoint, this behavior indicates that maximum exposure occurs during the initial phases of intervention, highlighting the importance of implementing control measures from the very beginning of operations.

Another relevant aspect highlighted by the study is related to the dimensional distribution of fibers. The results indicate a predominance of the respirable fraction, particularly in scenarios involving intense mechanical stress and degraded materials. Fine, elongated fibers with small diameters and high aspect ratios exhibit an increased potential for penetration into the alveolar region, conferring substantial toxicological significance. Therefore, not only total fiber concentration but also fiber morphology is critical in exposure assessment.

The identified correlation between material age and dispersion level confirms that degradation processes are cumulative and lead, over time, to an increased exposure risk. Older materials exhibit a reduced capacity to retain fibers, making them more susceptible to fiber release during processing activities. This observation supports the use of material age as an indicative risk parameter, in combination with physical condition assessment.

From a regulatory standpoint, the results must be interpreted in relation to the current European Union occupational exposure limit of 0.01 fibers/cm^3, which is significantly more restrictive than the historical limit of 0.1 fibers/cm^3. Under these conditions, even moderate dispersion levels may become relevant in terms of regulatory compliance and worker protection, highlighting the need to adapt work practices to the new legislative framework and actual risk levels.

From an applied perspective, the findings support the implementation of stringent preventive measures in activities involving materials that may contain asbestos. These include prior material identification and assessment, the use of wet working methods to reduce dispersion, application of local exhaust ventilation systems with HEPA filtration, air quality monitoring, and the use of appropriate personal protective equipment. Adequate worker training and strict adherence to safe working procedures are also essential.

Future research directions may include in situ evaluations, integration of numerical dispersion modeling, and correlation of experimental data with biological exposure indicators.

Overall, the results and interpretations presented contribute to a better understanding of asbestos fiber dispersion mechanisms and provide scientific support for the development of effective exposure prevention strategies in both occupational and environmental contexts.

6. REFERENCES

[1]. **Ridho, F. M., Ghani, H. N., Laksono, E. P., Faisal, A., Nurrahman, H. A.** (2024). Occupational asbestos-containing materials exposure and risk of asbestosis among construction workers. *Jurnal Ilmu Medis Indonesia, 3*(2), 65–73.

[2]. **Kurzhunbaeva, Z., et al.** (2024). Occupational exposure to chrysotile in an asbestos cement factory. *Environmental Health Perspectives*.

[3]. Danish Society of Occupational Medicine. (2013). Occupational asbestos exposure and lung cancer.

[4]. **Sørensen, M. K., et al.** (2025). A systematic review of outdoor airborne asbestos exposure. *Science of the Total Environment*.

[5]. **Franken, R., et al.** (2025). Comparing PCM, SEM and TEM for asbestos exposure assessment. *Annals of Work Exposures and Health*.

[6]. National Research Council. (2006). *Asbestos: Selected Cancers*. National Academies Press.

[7]. U.S. Environmental Protection Agency. (2020). Chrysotile asbestos systematic review.

[8]. ANSES. (2014). Occupational exposure to asbestos and health effects.

[9]. International Agency for Research on Cancer (IARC). (2012). *Arsenic, metals, fibres and dusts*.

[10]. Comisia Europeană. (2022). *Comunicare a Comisiei către Parlamentul European, Consiliu, Comitetul Economic și Social European și Comitetul Regiunilor privind depunerea de eforturi pentru un viitor fără azbest*. COM(2022) 488 final. EUR-Lex.

[11]. Comitetul European al Regiunilor. (2023). *Aviz privind propunerea de directivă privind azbestul*. EUR-Lex.

[12]. Hotărârea Guvernului României nr. 124/2003. *Privind prevenirea, reducerea și controlul poluării mediului cu azbest*. Monitorul Oficial nr. 182/2003.

[13]. JRC (Joint Research Centre). (2022). *Towards energy efficient and asbestos-free dwellings through deep energy renovation*. JRC129218.

[14**]. Obmiński, A.** (2022). Asbestos cement products and their impact on soil contamination in relation to various sources of anthropogenic and natural asbestos pollution. *Science of the Total Environment, 848*, 1572754.[1]

[15]. *Ordinul ministrului sănătăţii şi familiei nr. 536/1997 pentru aprobarea Normelor de igienă şi a recomandărilor privind mediul de viaţă al [2]populaţiei*. Monitorul Oficial nr. 140/1997.

[16]. **Virta, R. L.** (2006). *Worldwide Asbestos Supply and Consumption Trends From 1900 to 2003*. U.S. Geological Survey Open-File Report 2006–1290.

[17]. Legea nr. 319/2006 a securității și sănătății în muncă, cu modificările și completările ulterioare.

[18]. Hotărârea Guvernului nr. 580/2023 pentru modificarea și completarea HG 124/2003.

[19]. **Sali L.,** "Asbestos and disease – a public health success story?", *Scandinavian Journal of Work, Environment & Health*.

[20]. "Asbestos Exposure and Cancer Risk Fact Sheet", National Cancer Institute (NCI).

[21]. **Ridho F. M., Ghani H. N., Laksono E. P., et al.,** "*Occupational Asbestos-containing Materials Exposure and Risk of Asbestosis among Construction Workers"*, Jurnal Ilmu Medis Indonesia, 2024.

[22]. **Obmiński, A., et al.**, "Pollution of the environment and building interiors during asbestos removal", *Scientific Reports*, 2024.

[23]. **Aryal, A., et al.,** "Mitigation of Contamination and Health Risk: Asbestos Surveying, Removal and Disposal Practices", *Sustainability*, 2024.

[24]. "Global use of asbestos - legitimate and illegitimate issues", *Journal of Occupational Medicine and Toxicology*, 2020.

[25]. **Pira E, Donato F, Maida L, Discalzi G.** Exposure to asbestos: past, present and future. J Thorac Dis. 2018 Jan;10(Suppl 2):S237-S245. doi: 10.21037/jtd.2017.10.126.

[26]. **Frank, A.L.** Global use of asbestos - legitimate and illegitimate issues. *J Occup Med Toxicol* **15**, 16 (2020)

[27]. **Bağcı Ö.,** *"Evaluation of Asbestos in Terms of Occupational Safety in Urban Transformation",* Dergipark (Turcia), 2022.

[28]. **De Maria L., et al**., "Clinical investigation of former workers exposed to asbestos (1994-2020)", *Frontiers in Public Health*, 2024.

[29]. **Zhang Y.-L., et al.,** "Risk assessment of asbestos containing materials in old buildings, during demolition or remodeling", *Building and Environment*, 2021.

[30]. "Asbestos - World Health Organization (WHO) fact sheet".

[31]. **O'Regan P., et al.,** "*Asbestos Exposure and Compliance Study of Construction and Maintenance Workers* (Australia)", Safe Work Australia, 2010.