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Professor

AI-supported electron microscopy analysis of occupational asbestos exposure concentrations:

Needs and state of play!

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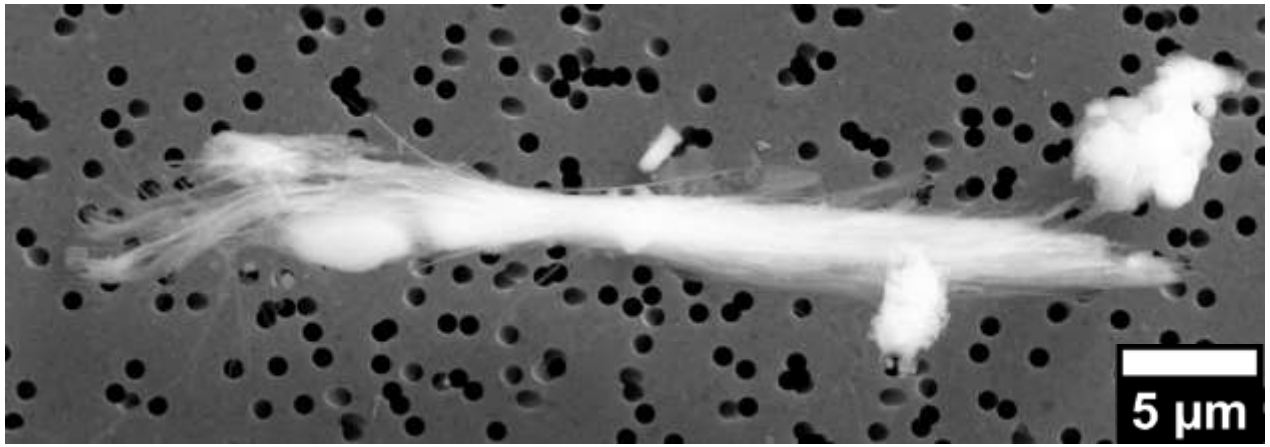
Outline

- **Background on asbestos, epidemiology, and the re-emerging health risk.**
- **The EU Directive 2023/2668 and new requirements.**
- **Considerations on the new requirements in the EU Directive 2023/2668 and consequences.**
- **A solution to meet the new analytical requirements for assessing asbestos exposure in the workplace.**

Asbestos – a serious occupational health problem from the past

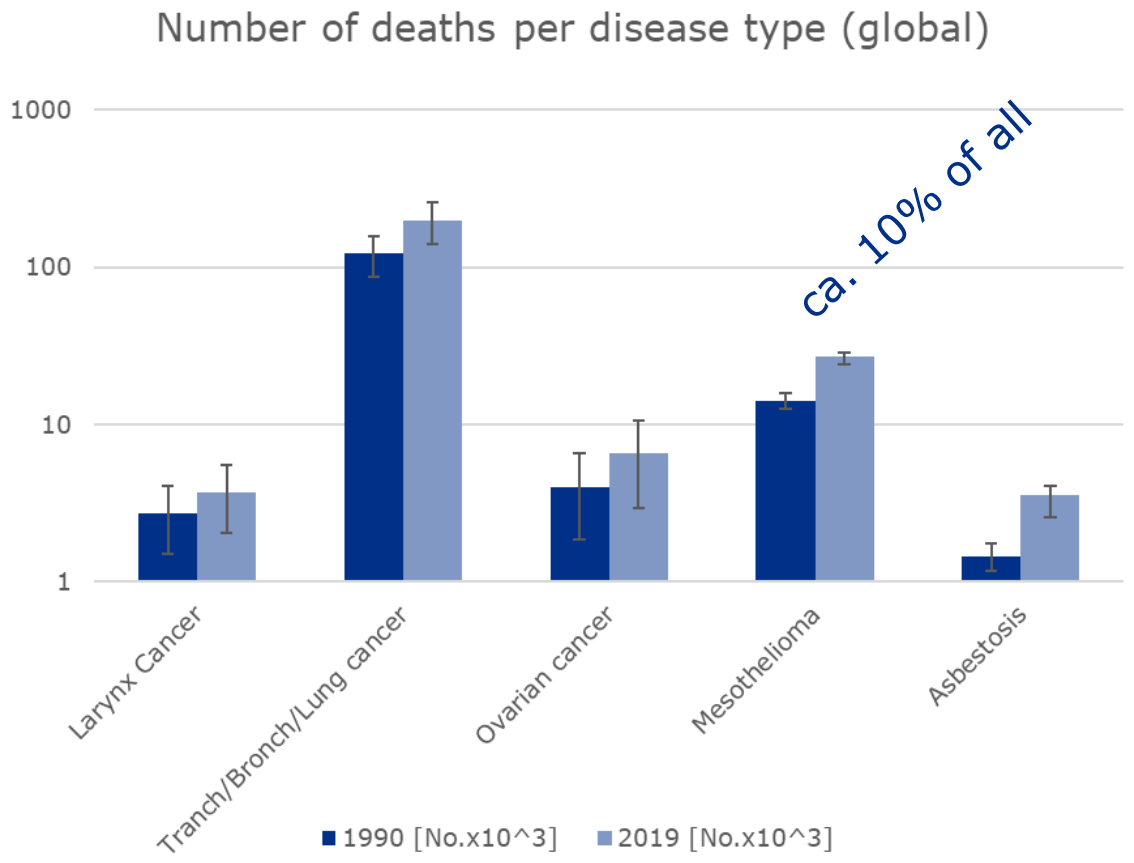


Asbestos: Minerals with fibrous nature

Amphiboles: actinolite, amosite, anthophyllite, crocidolite and tremolite

Serpentines: chrysotile

Banned use in Europe: Since 2005



Data from Miao et al. BMC Public Health (2024) doi: 10.1186/s12889-024-18099-4

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Asbestos – Problem not fixed! A serious re-emerging exposure!

European Commission

Renovation Wave

The European Green Deal

October 2020
#EUGreenDeal

To reduce emissions by at least 55% in 2030 and build the foundations for a climate neutral Europe by 2050, the Renovation Wave aims to **renovate 35 million inefficient buildings by 2030**.

85-95% of buildings in the EU are expected to still be standing in 2050. **Renovating them is essential to reducing emissions and energy use**.

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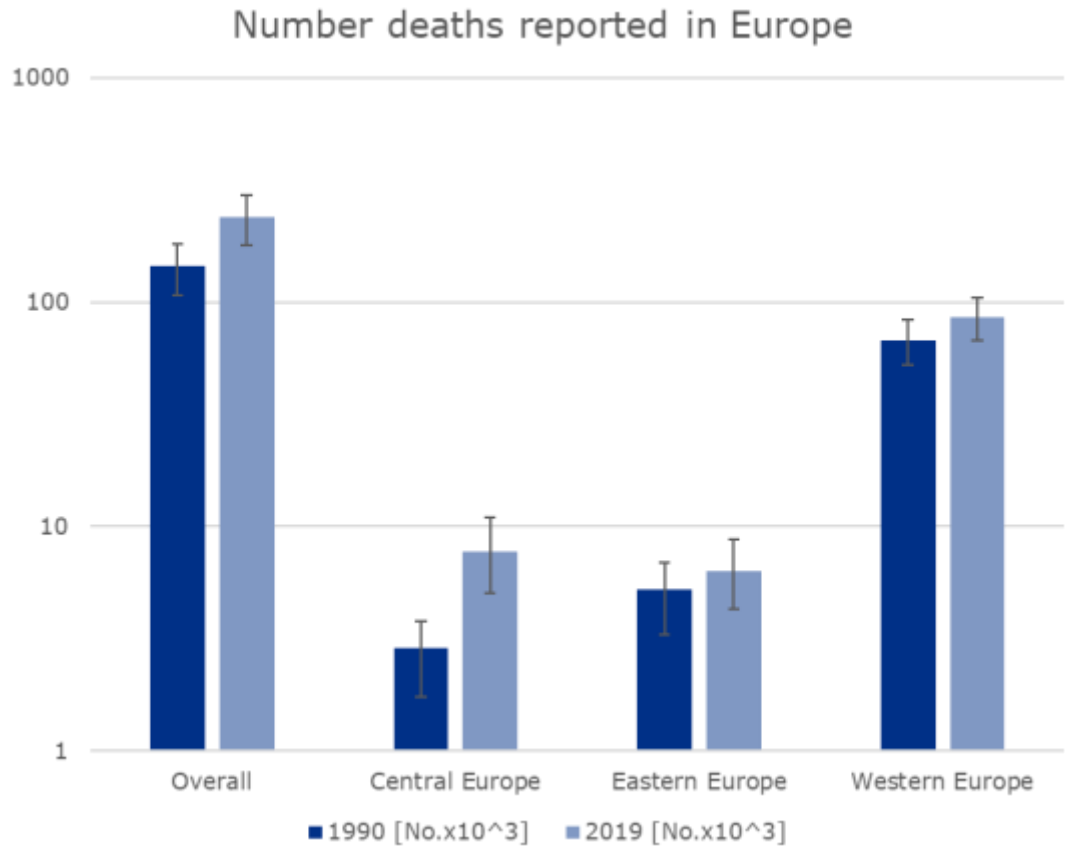
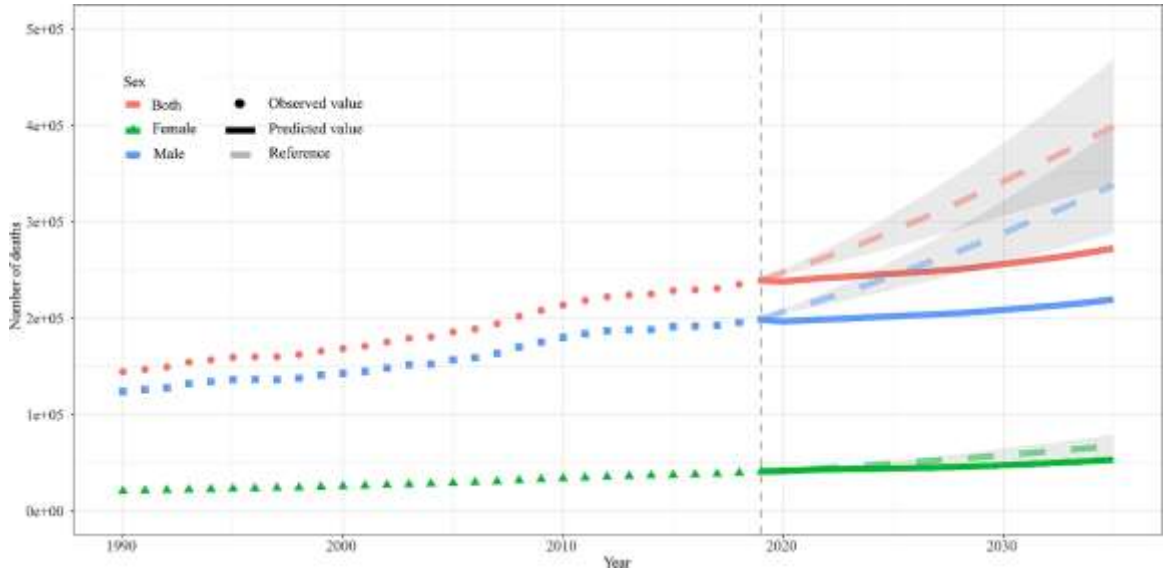
What is the future risk and risk mitigation?



Number of deaths reported and estimated globally



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Data from Miao et al. BMC Public Health (2024); doi: 10.1186/s12889-024-18099-4

The regulatory tool to manage the risk

Official Journal
of the European Union

EN

Series L

2023/2668

30.11.2023

DIRECTIVE (EU) 2023/2668 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL

of 22 November 2023

amending Directive 2009/148/EC on the protection of workers from the risks related to exposure to asbestos at work

THE EUROPEAN PARLIAMENT AND THE COUNCIL OF THE EUROPEAN UNION,

Disruptive changes in OELs and metrology

Until 20/12 2029
OEL = 0,01 f/ccm 8h TWA
WHO Fibers (D= 0,2-3µm; L > 5µm)
Methods: PCM or other equivalent or better method

1) OEL (21/12/2029a) = 0,002 f/ccm 8h TWA
WHO Fibers (D= 0,2-3µm; L > 5µm)
Aspect Ratio ≥ 3
Methods: SEM, TEM

2) OEL (21/12/2029b) = 0,01 f/ccm 8h TWA
Including Thin Fibers (D < 3µm; L > 5µm)
Aspect Ratio ≥ 3
Methods: SEM, TEM or alternative

No lower diameter limit for counting provided!

Asbestos types included: actinolite, amosite, anthophyllite, chrysotile, crocidolite, and tremolite

More fibres under consideration:
amphiboles: riebekite, winchite, and richterite and *zeolites:* erionite, flour-erionite

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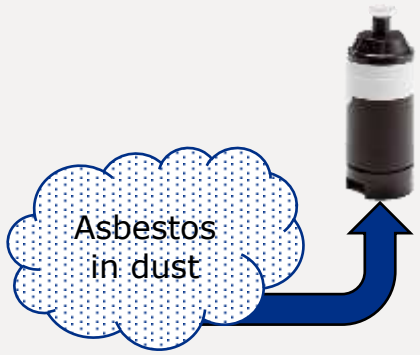
Disruptive questions to be clarified

- **What is the adequacy of the asbestos analysis methods and validity of existing standards?**
- **Are results obtained by the different methods comparable or can data conversions be made?**
  - Directive 2023/2668 requires transition from PCM by December 2029;
  - But Directive 2023/2668 requires change in OEL by December 2025 – *3 years ahead of EM method*;
- **Is the fraction of fibers <0,2 µm in diameter important and what is the consequence of choosing either of the proposed OEL's in Directive 2023/2668?**
- **What are the practical requirements and solutions for determination of asbestos concentrations at the new OELS?**

Adequacy of existing standard methods for asbestos analysis



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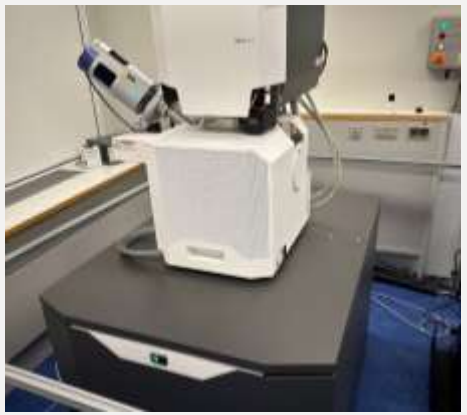

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Parameter	PCM	SEM (EDS)	TEM (SAED & EDS)
Fiber-(type)-specific	No	Yes, w/ EDS	Yes, w/ EDS and SAED
Standard method detection limit	> 0.2 - 0.25 µm; (measurable 0,6-0,75 µm)	0.1 - 0.2 µm (real ≤ 0,01 µm)	0.01 - 0.02 µm (today ≤ 0,001 µm)
Detection limit (NOT quantification limit)	approx. 0.002 f/m³ * Realistic < 0.005 f/m³	approx. 0.0001 – 0.0002 f/cm³ **	approx. 0.001 f/cm³ **
Relevant standards or protocols	WHO, 1997; NIOSH 7400: 1994; HSE, 2021	ISO 14966: 2019; VDI 3492: 2013	ISO 10312: 2019; ISO 13794: 2019 (aspect ratio 5:1, minimum length 0.5 µm)
(Counting rules)	(WHO: >5 µm length and <3 µm width; aspect ratio 3:1)	WHO: >5 µm length and 0,2 - 3 µm width; aspect ratio 3:1) ***	*AFNOR X43-050:2021 (aspect ratio 3:1, min. length 0.5 µm)*

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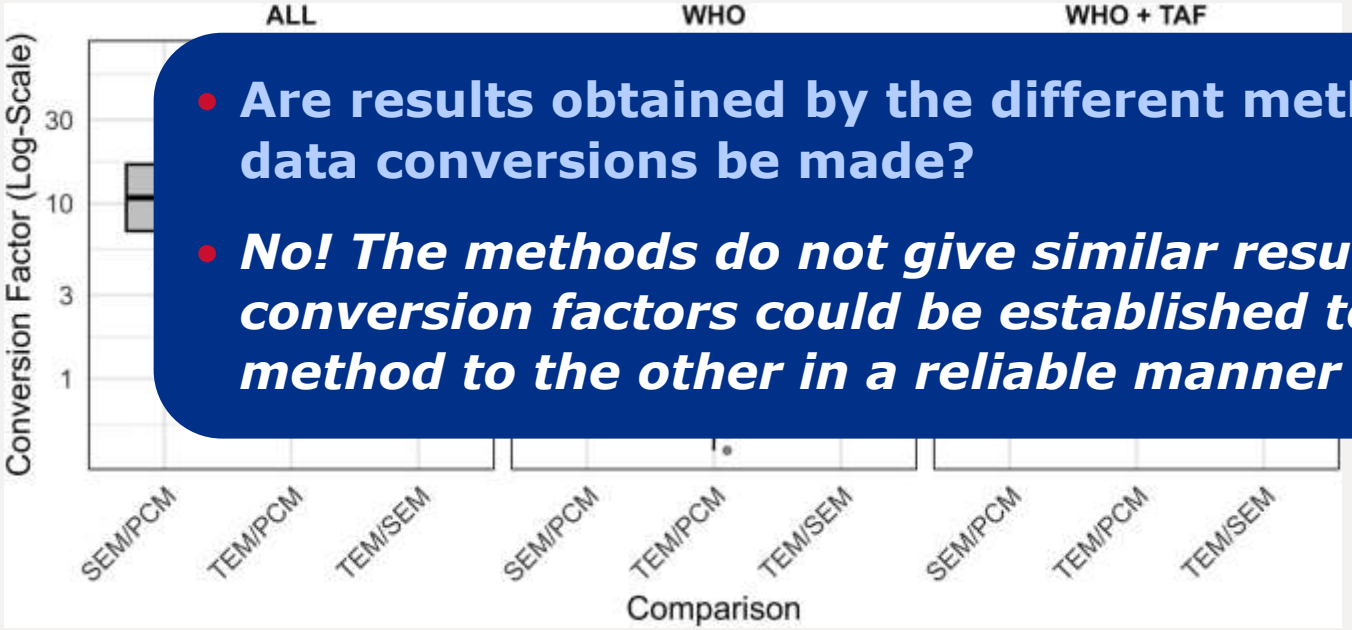
* > 5,000 fibres/m³ in presence of other fiber types ISO 8672:2014. NIOSH 7400: 0,0027 fibre/cm³ at 1 m³ in low dust air.
** In low dust air; *** ISO 14966:2019 recommends ISO 10312 for fibres < 0,2 µm width.

Modified from Franken et al. AWEH (2024): https://doi.org/10.1093/annweh/wxaf023

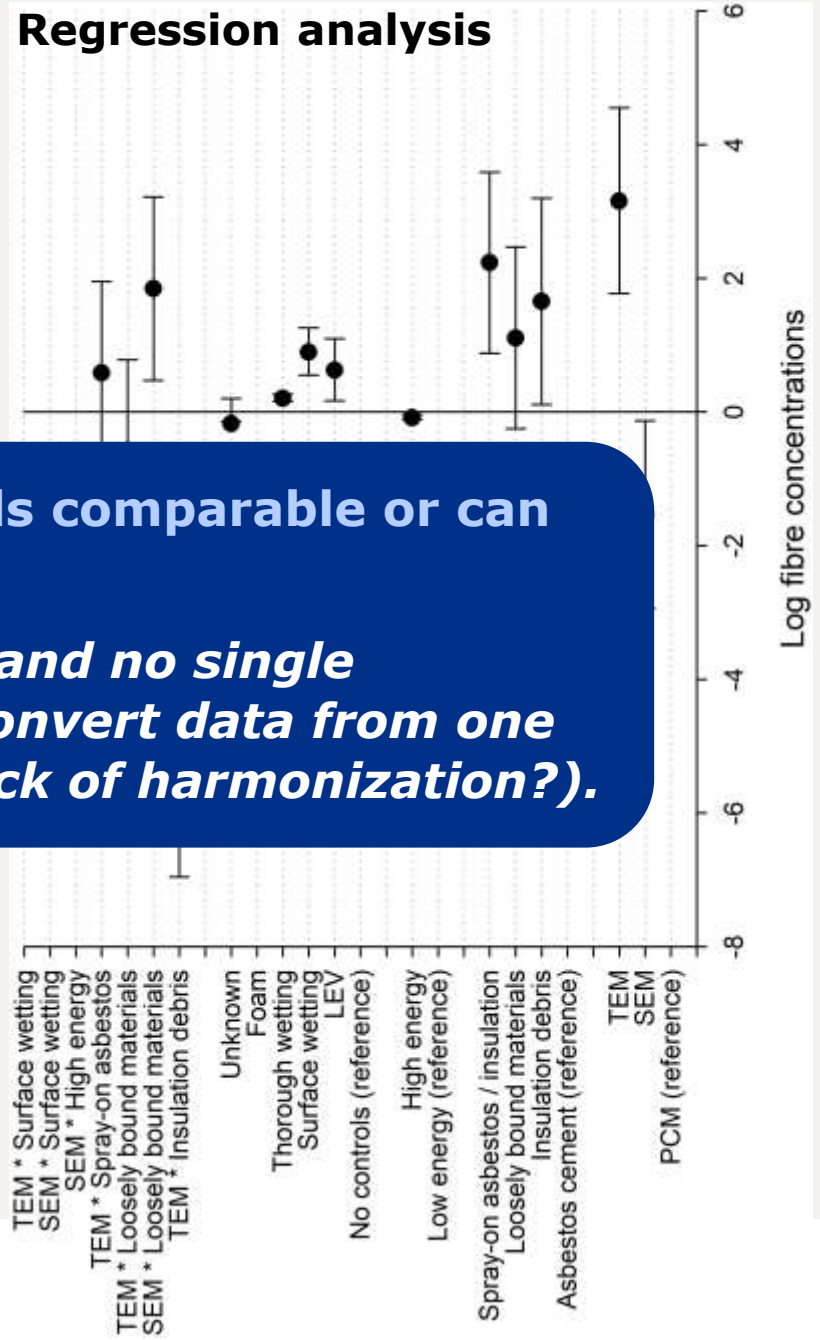
Comparability between methods

Direct test comparisons



- **Are results obtained by the different methods comparable or can data conversions be made?**
- ***No! The methods do not give similar results and no single conversion factors could be established to convert data from one method to the other in a reliable manner (lack of harmonization?).***

Regression analysis



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Franken et al. AWEH (2024): https://doi.org/10.1093/annweh/wxaf023

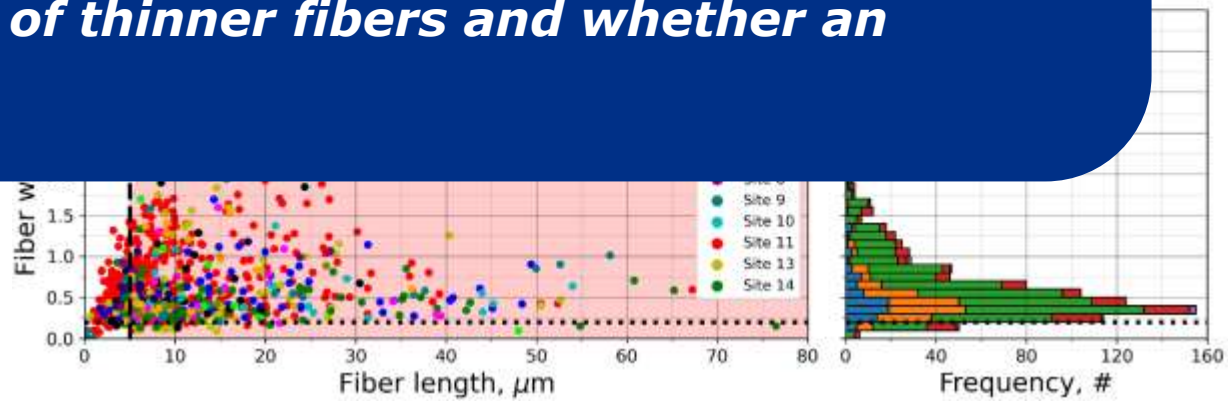
Fraction of fibers thinner than 0,2 µm?
Fiber dimensions and consequnces by selection of different OELs

Franken et al. AWEH (2024):
http

Brostrøm et al. J Haz Mat Advances (2025):

- **Is the fraction of fibers <0,2 µm in diameter important and what is the consequence of choosing either of the proposed OEL's in Directive 2023/2668?**
- ***Limited data exist! It appears that the thin fibre fraction may be up to at least 45%. This does not justify an OEL of 0,01 f/cm³, including thin fibers < 0,2µm.***
- ***Dedicated and properly designed studies are needed to investigate whether certain scenarios would benefit inclusion of thinner fibers and whether an associated OEL should be > 0,002 f/cm³***

ACM							
Insula							
Asbes							
	Crocidolite	TNO	FEG-SEM	All	24	30% to 45%	20% to 35%
		STAMI	SEM	WHO	92	15% to 30%	30% to 45%
Flange/gasket	Chrysotile	TNO	FEG-SEM	All	45	30% to 45%	20% to 30%



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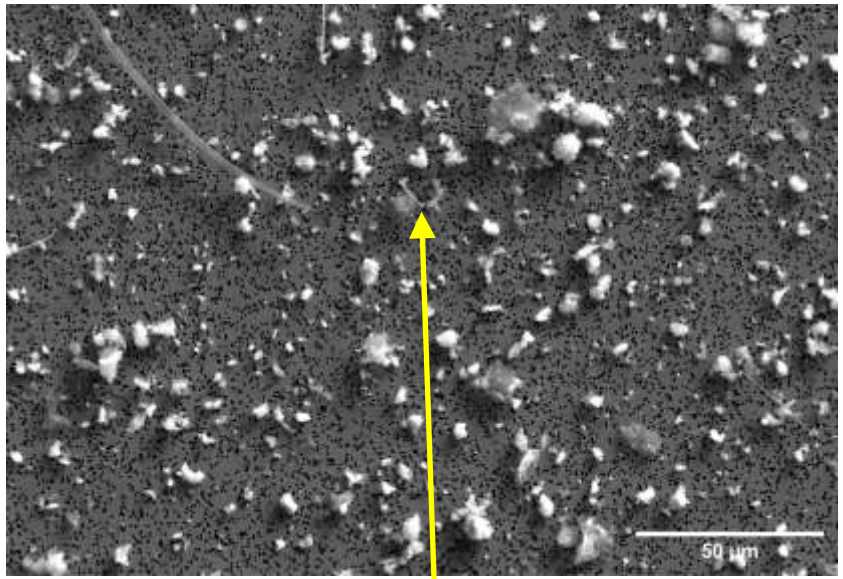
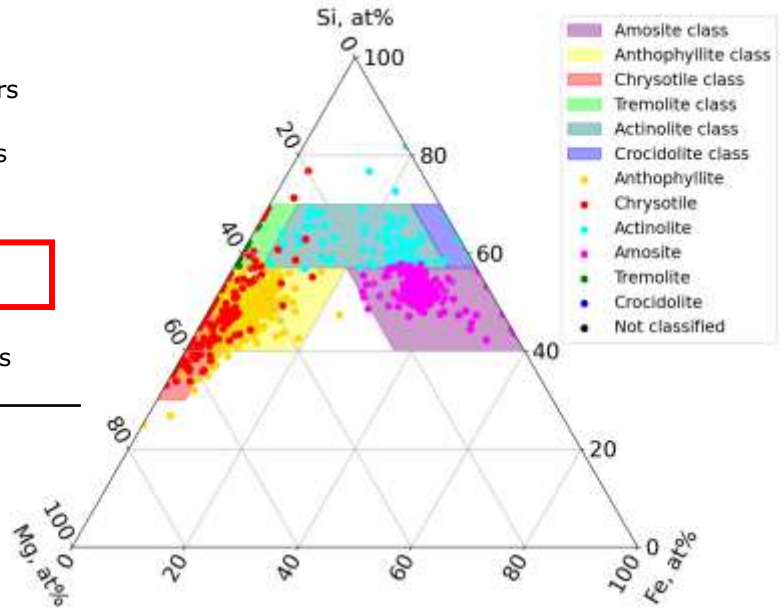
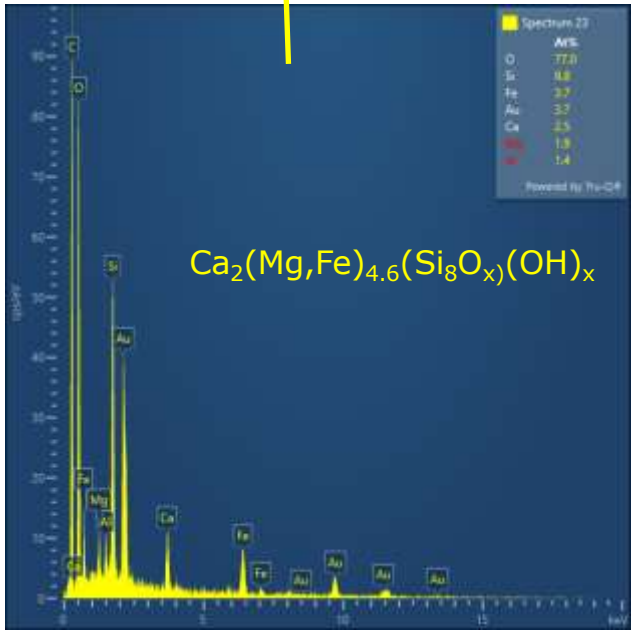
Practical analytical requirements (in SEM)

1. Acquire overview image (e.g., 50 nm/px)
2. Visual fiber identification
3. Measure the fiber dimensions for inclusion/exclusion
4. Acquire EDS spectrum (point and ID)
5. Assess composition in relation to known asbestos formulas
6. Register the asbestos type, morphology class, and dimensions.



Asbestos type	Formula	Morphology
Chrysotile	$Mg_3(Si_2O_5)(OH)_4$	Flexible fibers
Amosite	$Fe_7(Si_8O_{22})(OH)_2$	Brittle needle-like fibers
Crocidolite	$Na_2Fe_5(Si_8O_{22})(OH)_2$	Fine needle-like fibers
Tremolite	$Ca_2Mg_5(Si_8O_{22})(OH)_2$	Needle-like fibers
Actinolite	$Ca_2(Mg,Fe)_5(Si_8O_{22})(OH)_2$	Needle-like fibers
Anthophyllite	$(Mg,Fe)_7(Si_8O_{22})(OH)_2$	Long needle-like fibers





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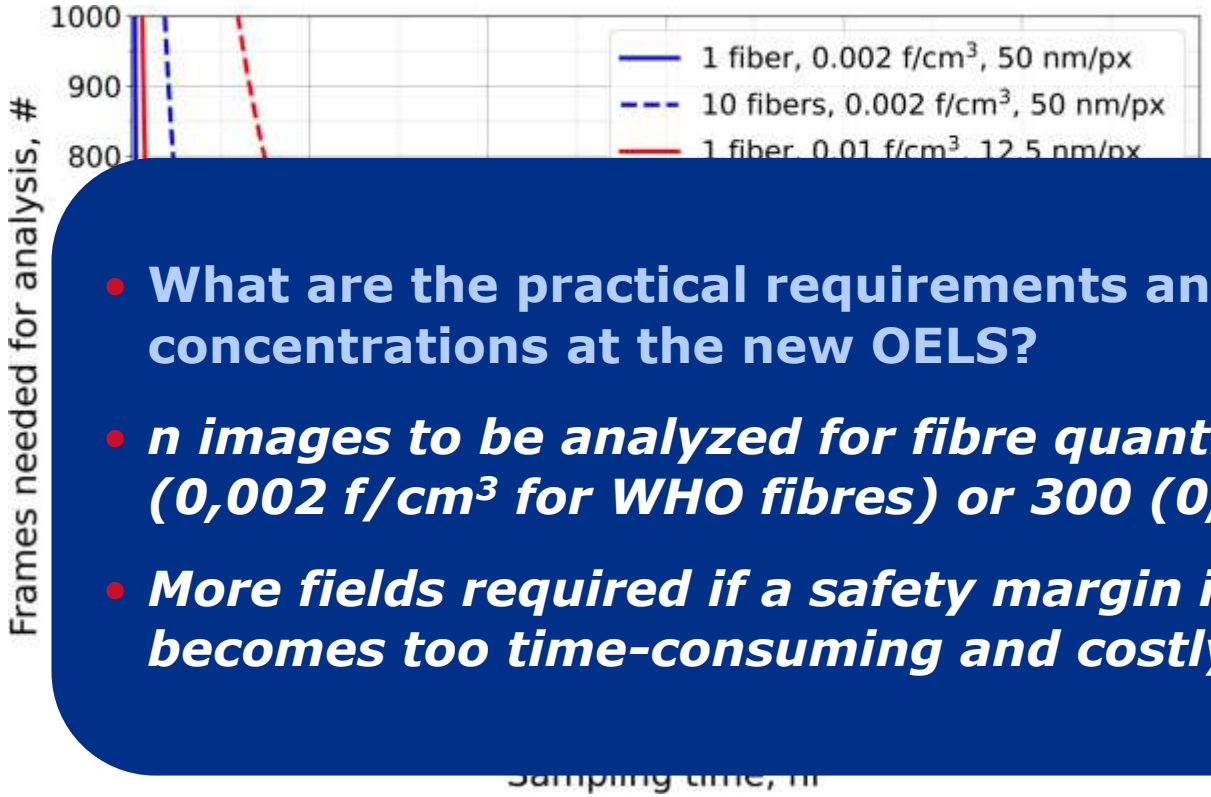
Practical analytical requirements (in SEM)

Sampling time / Number of image frames to analyze at different OELs



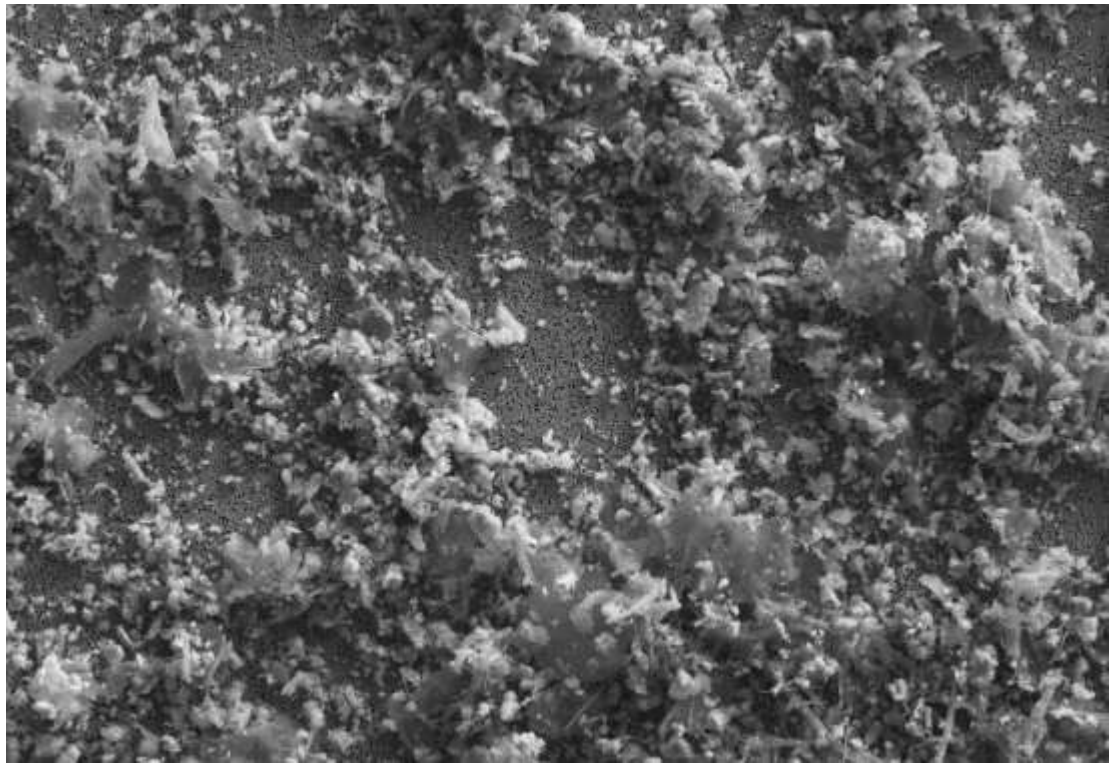
Conditions for calculations

The two scenarios both used a sampling standard flowrate of 1.9 l/min and 8192 x 5632 pixel images.

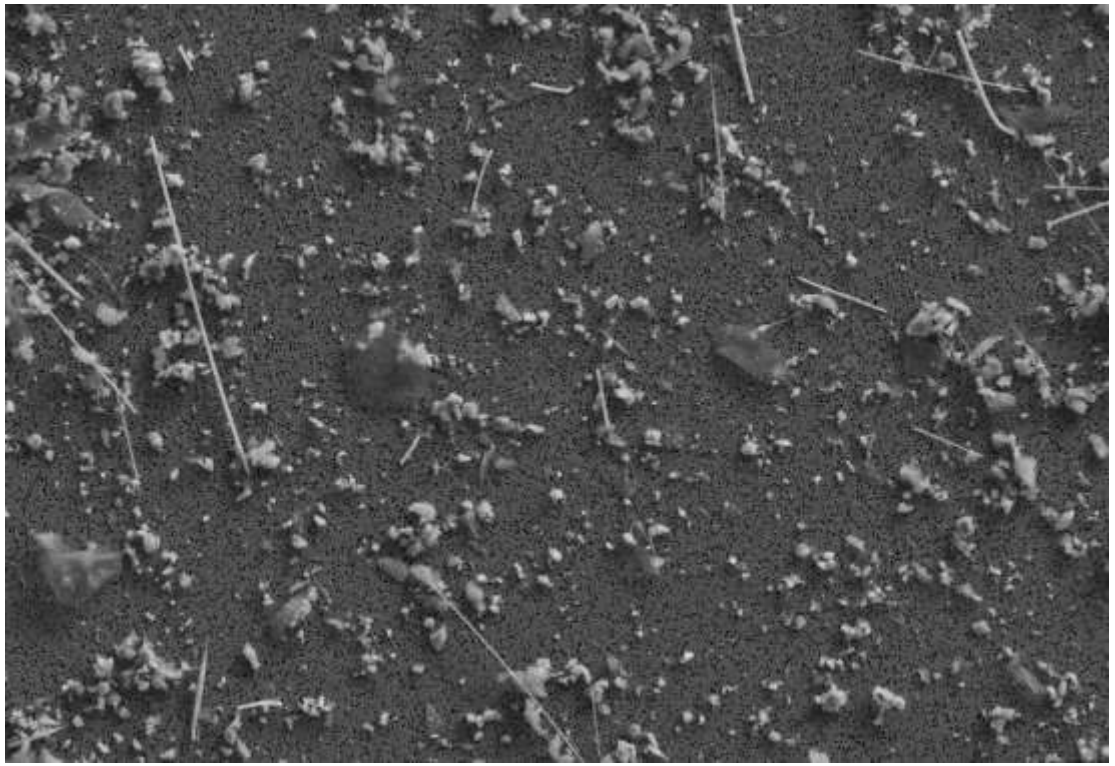
- **What are the practical requirements and solutions for determination of asbestos concentrations at the new OELS?**
- ***n images to be analyzed for fibre quantification at OEL levels rapidly exceed 100 (0,002 f/cm³ for WHO fibres) or 300 (0,01 f/cm³; thin fibres <0,2µm)***
- ***More fields required if a safety margin is needed (e.g., X10). The analysis becomes too time-consuming and costly for practice.***

Increasing sampling volume (lower n images required) is not a solution due to overloading (fx in construction environments!

Removal of ceiling plates;
100 minutes sampling @ 1,9LPM (190L)



Cleaning after removal asbestos cement roof,
111 minutes of sampling @ 1,9LPM (210,9L)



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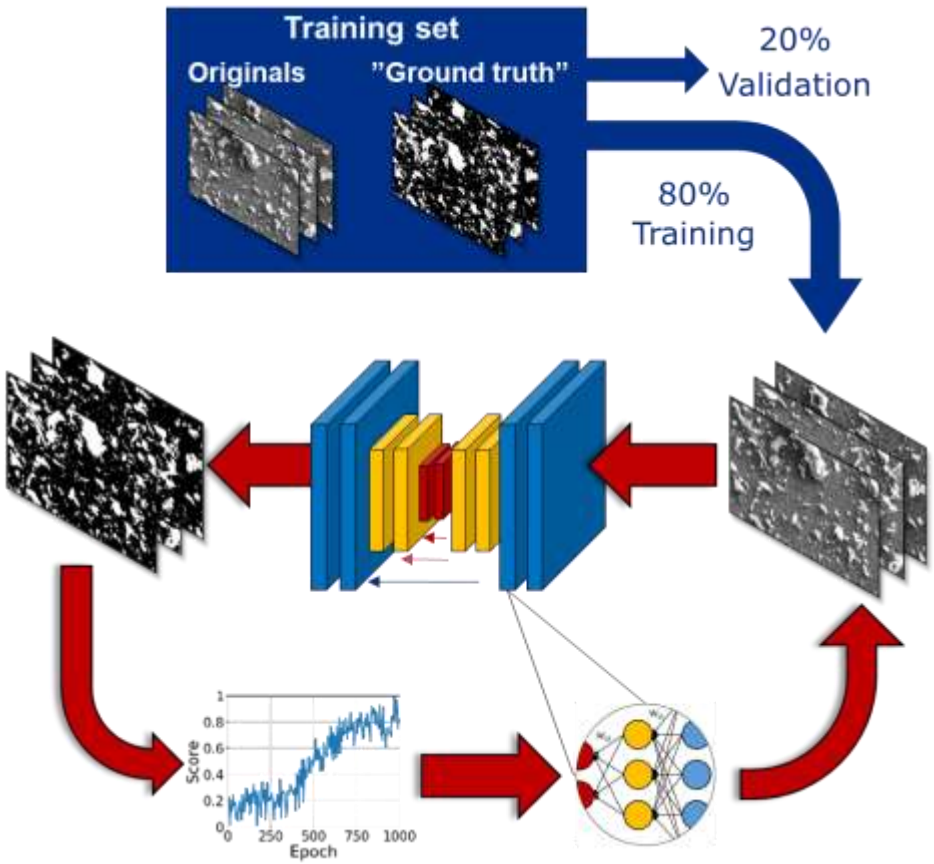
Solution: AI-assisted microscopy / data-analysis to enable cost-efficient analysis.



Roadmap (main steps forward)

- **Input data**
  - Comprehensive data set (images and chemical spectra) for a specific instrument (lab approach) or a range of instruments and settings (general approach).
- **Decide on AI-approach**
  - Particles → fiber ID → EDS confirmation (online or 2-step SEM)
  - Fiber ID → EDS confirmation (online or 2-step SEM)
  - SE-EDS Map-based → Asbestos ID (offline)
- **Training and testing**
  - Establish ground truth for training the AI-model
  - Train
  - Validate
  - Performance testing
- **Standardization**
  - Definition of criteria and definition of use
  - Interlaboratory validation
  - Standard development and approval

Advanced labs are approx. here

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Conclusions

- **Existing standard methods are not validated for either of the new asbestos OEL's and inclusion criteria in Directive 2023/2668**
- **Results from using the PCM, SEM, and TEM asbestos fibre analysis methods are *not* comparable and data conversions is *not* possible. Laboratory methods may not have been fully harmonized**
  - Establishment of proper EM methods is urgent, because PCM is insufficient and Directive 2023/2668 requires change in OEL by December 2025 – *3 years before EM is requiered*.
- **The fraction of thin fibers (<0,2 µm) may be important, but from exisiting data the high OEL for thin fibers in Directive 2023/2668 does not offer the same protection as the low OEL for WHO fibers. Further well-designed studies are needed!**
- **Due to manual EM analysis and associated cost will be high, AI-assisted electron microscopy and associated standards must be established as soon as possible to ensure that good compliance measurements are done in the future for worker protection.**

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Thank you for your attention

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