Asbestos exposure measurement investigation using analytical transmission electron microscopy (ATEM)

Summary of results and recommendations

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August 2011

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1. Background

In February 2009, the French Agency for Environmental and Occupational Health Protection (AFSSET[1]) published a report on the toxicity of short asbestos fibres (SAFs) and thin asbestos fibres (TAFs). Its conclusions confirmed the carcinogenic nature of TAFs and did not exclude the toxicity of SAFs. Following this report, in September 2009, the Agency published recommendations concerning the lowering of the airborne asbestos occupational exposure limit value (OELV). It recommended reducing this value by a factor of 10: i.e. an 8-hour OELV of 10 fibres per litre (f/l).

For the occupational environment, one of AFSSET's recommendations referred to the modification of the analysis method for measuring the level of airborne asbestos fibres in the workplace, using analytical transmission electron microscopy (ATEM), in order to include the thinnest fibres (less than 0.2 µm in diameter) not visible by phase-contrast microscopy (PCM), which is routinely used, and to identify the nature of fibres observed.

However, in order to make ATEM counts operational, a methodology for sampling airborne asbestos in the occupational environment first had to be defined, so that all the different ranges of concentration likely to be present could be accurately analysed.

In this context, from November 2009 to October 2010, the French Directorate-General for Labour (DGT) launched an asbestos exposure measurement investigation using ATEM.

The objectives were in particular :

- to establish a method and validate the feasibility of sampling airborne asbestos fibres in the occupational environment with an ATEM analysis ;
- to ascertain the dust levels generated by the various "asbestos-containing material/technical process" combinations when measured by ATEM, in order to implement technical rules minimising the release of dust into the air and determine protective measures adapted to these levels ;
- to establish the particle size distribution of the different classes of fibres[2] on the sampling filters (WHO-defined fibres are those currently counted in the occupational environment, since TAFs and SAFs are not visible by phase-contrast microscopy – PCM).

INRS, in cooperation with the DGT; the *Laboratoire d'études des particules inhalées de la Ville de Paris* (LEPI – laboratory specialised in inhaled particles research); the *Caisse nationale d'assurance*

[1] Since then, AFSSET has merged with the French Food Safety Agency and is now the French Agency for Food, Environmental and Occupational Health and Safety (ANSES).

[2] The dimensional criteria for fibres taken into account in the asbestos investigation protocol correspond to those defined in the AFSSET report :

- WHO-defined fibres are over 5 µm in length, between 0.2 and 3 µm in diameter (size detectable by PCM) with an aspect ratio greater than or equal to 3:1 ;
- Thin asbestos fibres (TAFs) are longer than 5 µm and have a diameter between 0.01 and 0.2 µm;
- Short asbestos fibres (SAFs) are shorter than 5 µm, have a diameter below 3 µm with an aspect ratio greater than or equal to 3:1.

maladie des travailleurs salariés (CNAMTS – French National Health Insurance Fund for Salaried Workers); and the measurement organisations represented by the *Syndicat du retrait et du traitement de l'amiante en place et des autres pollutants* (SYRTA – asbestos and other pollutants removal and treatment association), participated in the elaboration of the protocol for airborne asbestos sampling and measurement by ATEM. INRS then drew up the findings analysis report and issued occupational health recommendations with regard to operations conducted on asbestos containing materials (ACMs).

2. ATEM investigation

This investigation was conducted on worksites in actual work situations.

The protocol defined 25 worksite types (material/removal technique combinations) with five worksites for each type. The sampling strategy consisted of collecting two two-hour personal samples twice per day, i.e. a total of four measurements per worksite.

These worksite types covered the removal, in indoor and outdoor settings, of friable and non-friable ACMs, as well as maintenance conducted on these materials[3].

The ATEM measurement method used stemmed from the French standard NF X 43-050 *Qualité de l'air – Détermination de la concentration en fibres d'amiante par microscopie électronique à transmission – méthode indirecte* (Air quality – Determination of the concentration of asbestos fibres using transmission electron microscopy – Indirect method) – January 1996.

The analysis was to be conducted on WHO fibres, SAFs and TAFs, and the results [WHO+TAFs] were expected to give perspective to the possibility of adopting ATEM for checking compliance with the 8-hour OELV. For each measurement, the airborne asbestos fibres were classified under the amphibole or serpentine family.

Prior to the start of the measurement investigation, the protocol was presented to accredited laboratories in charge of asbestos sampling and analysis, which were to be addressed by companies wishing to participate in the study.

A labour inspection officer checked for compliance with the sampling protocol at the worksite.

The distribution of worksites and the de-identified recording of data were performed by SYRTA, which, on that occasion, deployed a computerised tool to centralise the findings.

[3] The French Labour Code distinguishes between two types of activity:
- removal or containment of ACMs, referred to as "sub-section 3" activities;
- maintenance operation on ACMs and asbestos-bearing land, referred to as "sub-section 4" activities.

3. Results

Voluntary participation of companies only enabled 265 test results to be collected, i.e. half of the results expected, corresponding to 29 worksite types. For some classifications, there were no corresponding worksites, while for others, there were more samples or worksites than initially intended.

The table below presents the global results for all the situations for each category and class of fibre, with minimum values, arithmetic means, and median and maximum values, measured in fibres/litre (f/l).

		Min (f/l)	Arithmetic mean (f/l)	Median (f/l)	Max (f/l)
WHO (15%)	serpentines	1.48	539	18	16,300
	amphiboles	1.47	337	5	23,025
	Asbestos[4]	1.48	866	38	23,025
TAFs (17%)	serpentines	1.48	1,742	21	51,450
	amphiboles	1.47	91	5	6,358
	Asbestos	1.48	1,822	24	51,450
SAFs (68%)	serpentines	1.48	13,602	190	256,072
	amphiboles	1.47	1,220	5	89,655
	Asbestos	1.48	14,811	356	256,072

For the most part, worksite activities concerned asbestos removal. Only one situation involving a "maintenance operation" on an ACM was analysed.

The results for certain types of worksites for which very few operations were conducted (especially when there were few samples) should be interpreted with caution.

Nevertheless, the study showed that the highest fibre dust levels [WHO+TAFs] occurred with the removal of :

- asbestos-containing plaster, regardless of the technique used, with average concentrations higher than 11,000 f/l, and a maximum concentration of 60,000 f/l ;
- sprayed asbestos (though composed of only amphiboles – sprayed chrysotile could have generated higher quantities of TAFs close to the values observed for asbestos-containing plaster because of their capacity to generate fibrils that are thinner than amphiboles), with average concentrations of over 6,000 f/l, and a maximum concentration of 29,000 f/l ;

[4] The term "asbestos" is used when all types of fibres are being referred to (amphiboles + serpentines).

- paint and coating, with average concentrations of over 3,000 f/l, and a maximum concentration of 6,300 f/l ;
- materials in damaged buildings, with an average concentration of over 2,600 f/l, and a maximum concentration of 21,000 f/l.

The results were subjected to a descriptive statistical analysis, which was expected to discriminate between certain techniques. However, the quantity of data and their distribution in the different types did not allow for a thorough exploratory statistical analysis.

The only statistical correlations that enabled characterisation of asbestos fibre dust [WHO+TAFs] concerned :

- the removal of asbestos-containing plaster (generating a high level of dust with regard to the protocol criteria) ;
- the removal of asbestos-containing paint and coating (generating a moderate level of dust with regard to the protocol criteria).

As regards the wearing of respiratory protective equipment (RPE), it should be specified that respiratory protection conditions were imposed by the protocol according to three anticipated levels of dust[5] which were predefined on the basis of expert knowledge. The highest level of dust required the use of compressed air line breathing apparatus.

Although PCM analyses were not planned within the framework of the investigation, “WHO” fibre count results that until then had been obtained by PCM could still be compared with the ATEM study data for the same category of fibres, using the 5,274 results recorded in the SCOLA database[6].

For “WHO” fibres with the same particle size distribution criteria (for a diameter between 0.2 and 3 µm), PCM underestimates the level of worker exposure compared to the ATEM method.

[5] Low (less than 1,000 f/l) - Moderate (between 1,000 and 10,000 f/l) - High (above 10,000 f/l).

[6] Since the entry into force of the French ministerial order of 4 May 2007 on the measurement of the concentration of airborne asbestos fibres in the workplace and the requirements for the accreditation of laboratories, the results of these measurements have been stored in the SCOLA (system for collecting data gathered by accredited bodies) database managed by INRS.

4. Conclusions

In conclusion, the analysis of the results revealed the following :

- On average, the proportion of TAFs was equivalent to that of WHO fibres (17% and 15% respectively of all fibres counted) ;
- The majority of fibres were SAFs representing an average of 68% of the fibres counted. The maximum concentration for this category of fibres was 250,000 f/l ;
- Most of the fibres analysed belonged to the serpentine family (chrysotile), except for one worksite type (removal of sprayed asbestos), in which only amphiboles were present. This occurrence was rather unusual, because in France, the type of fibres mostly used (95%) was chrysotile ;
- PCM, which is the method currently used to determine fibre concentration for comparison with the exposure limit in the workplace air (OELV), underestimates the level of worker exposure compared to the ATEM method :
    - ✓ for fibres with the same particle size distribution ("WHO" fibres with a diameter between 0.2 µm and 3 µm) ;
    - ✓ because of the proportion of TAFs (fibres with a diameter between 0.02 and 0.2 µm, observable only by ATEM) which doubles on average the number of fibres counted ;
- During the removal of asbestos-containing plaster, taking into account the average proportion of fibres [WHO + TAFs], the protection factors for the respiratory protection devices (including compressed air line breathing apparatus) used in asbestos worksites do not guarantee worker exposure lower than the current OELV of 100 f/l pursuant to occupational health recommendations ;
- Considering the maximum levels measured, the preceding observation also applies to the removal of sprayed asbestos, asbestos-containing paint and coating, operations in damaged buildings, and operations in asbestos cement pipes and roofing ;
- To comply with the OELV of 10 f/l as recommended by AFSSET taking TAFs into account, the respiratory devices used in work situations must have a protection factor[7] of at least 6,000 for the most polluting operations, given that the protection factor of the most effective devices available on the market (compressed air line apparatus) is lower than 2,000 ;
- The methodology for sampling and preparing the samples for analysis by ATEM enables the wide range of dust levels (from the lowest to the highest) observed in this investigation to be measured.

[7] The protection factor is defined as the ratio of the concentration of air contaminant outside the respirator to that inside the respirator.

5. Recommendations

Based on the observations made during the course of the study, INRS recommends in terms of :

- **Metrology and OELV compliance checks** :

- Using the ATEM counting method instead of PCM ;
- Taking TAFs into account in OELV compliance checks ;
- Setting an 8-hour OELV using the ATEM counting method ;
- Changing the exposure measurement procedure by limiting the number of measurements for each type of situation, but by improving the quality of measurements and adopting a method that can draw on the method described in the French ministerial order of 15 December 2009 on OELV compliance checks ;
- Increasing the reliability of asbestos dust measurements through the process of accreditation of laboratories in charge of asbestos exposure assessments ;
- Creating a specific training for staff in charge of the sampling strategy in laboratories responsible for sampling and analysis, with a view to improving the quality of checking services and harmonising national practices.

- **Prevention measures :**

- Not removing certain materials that are tightly bound and release too many fibres due to the removal techniques used, but containing them and ensuring their traceability ;
- Making available the results in the SCOLA database that centralises the data resulting from company experience in order to pool measurements of dust levels generated according to each worksite classification ;
- Determining the prevention actions to be implemented based on the results of checks ;
- Setting up windows around work areas to enable surveyors to view the worksite from outside the polluted area, and in particular to supervise sampling conducted by the operators without being exposed ;
- Improving traceability through a systematic and thorough identification of ACMs prior to work and improving the methods for compiling and updating the technical asbestos report ;
- Implementing in each company involved a programme for selecting and managing respiratory protection devices.

- **Methodology and technique :**

- Developing removal techniques that avoid direct intervention of operators ;
- Creating more effective personal protective equipment.

- **Knowledge acquisition :**

- Conducting studies in order to establish protection factors of respiratory protection devices in work situations based on ATEM analyses, targeting first and foremost the most effective devices (air compressed breathing apparatus) and the most often used devices (powered filtering devices classified TM3P) ;
- Continuing to acquire knowledge about dust levels (measured by ATEM) generated by “maintenance operations” on ACMs (sub-section 4) ;
- Pursuing studies on the toxicity of SAFs.