

## **The extent, types and quality of the exposure data associated with the industrially exposed asbestos worker cohorts.**

### **Purpose**

1. This Annex is focused on examining and assessing the airborne asbestos concentrations in the workplace that the workers in the quantitative asbestos cohorts were exposed to.

### **Background**

2. There are six naturally occurring minerals, which when they occur in an extreme fibrous habit (asbestiform) are regulated as asbestos. All six regulated types of asbestos are hazardous, category 1 carcinogens (known to be carcinogenic to humans) and have the potential to cause harmful diseases of the lung, if a person breathes in respirable airborne asbestos fibres. The risk of lung cancer and mesothelioma are dependent on a combination of the cumulative exposure (i.e. the frequency, duration and magnitude of the airborne fibre concentration over time), the time since first exposure and the type of asbestos. The onset of disease is delayed for many years with typical lag times of between 20 – 60 years.

3. For lung cancer the cumulative exposure in units of f.years/ml (airborne fibre concentration (f/ml) x duration of exposure (years)) is correlated with disease if an appropriate lag time is used. For mesothelioma, the age since first exposure is more important for modelling the risk.

4. There are some 20 industrial cohorts of asbestos workers, which have been used in quantitative epidemiological studies to derive asbestos dose-response relationships. Various selections of these studies have been used in the four most well-known risk models. These are summarised in Table 1. The models have been developed from reviews and meta-analyses of the epidemiology and the published dose-response relationships from the quantitative studies.

5. The risk models base their extrapolation on the use of an additive risk model for lung cancer and mesothelioma, using a relative risk model for lung cancer and an absolute risk model for mesothelioma. The later reviews and model benefit from increased follow-up of the cohorts. Substantial differences in the analyses arise from a variety of factors including:

- whether the different asbestos types are assessed separately,
- how the cumulative exposure are calculated,
- how the effects of smoking are taken into account,
- the number of cohorts used,
- the relative importance assigned to different cohorts,
- the type of regression curve fitted to the data, etc.

**Table 1: Summary of asbestos risk models in current use**

<b>Model and Date published</b>	<b>Asbestos Types</b>	<b>Dose response curve fitted</b>	<b>Use/availability</b>
EPA –IRIS EPA, 1986 & 1993	Mixed	Linear	EPA, web site gives some risks values.
HEI Health Effects Institute, 1991	Mixed	Linear	Partly embedded in HD and BC models also used separately e.g. IOM Armley report.
HD Hodgson and Darnton, 2000	Chrysotile Amosite Crocidolite	Sub-linear & supra-linear for peritoneal.	Used for HSE for risk assessment (e.g. CAWR, 2002 & CAR, 2006)
BC Berman and Crump, 2006	Chrysotile Amphiboles	Linear	Developed for EPA superfund subject to EPA review 2006, not widely used.

6. The method and degree of detail used in the analysis of airborne asbestos concentration and the exposure data, will significantly determine the shape and slope of the best-fit dose-response curves and the estimated risk when extrapolated to lower exposures. For instance the HD model derives a cohort average for both airborne concentration and the duration of employment, to give an average cumulative exposure for the entire cohort. The BC model uses a more detailed analysis of job specific exposure history and the duration of exposure, to derive cumulative exposures. In the BC model the differences in the data available between cohorts, was expressed as the uncertainty in the original data. Their analysis consistently attached a much higher uncertainty to the exposure data than any other variable.

7. Many authors of the asbestos cohort studies, state that the magnitude of the airborne concentration in the industrial environment was by far the greatest uncertainty. This uncertainty is primarily due to the long time since first exposure occurred (often between 1920 – 60). This is due in part to the extended lag times before disease occurs (20 – 60 years) and many of the epidemiological studies being carried out in the 1970s and 80s.

8. Some of the main difficulties in assessing the airborne fibre concentration are:

- The lack of air concentration measurements, especially before 1950;
- A variety of monitoring methods being used up to the 1970s;
- A widespread use of area sampling rather than personal sampling;
- The biological relevance of the current measurement indices;
- The validity of the conversion between different indices.

## Summary of airborne concentrations for the quantitative cohort studies

9. For ease of reference a summary of the airborne fibre concentration data reported in the cohort studies are presented in Table 2. The values have been divided into three phases for each cohort (early, middle and late). The measured values have all been converted to PCM equivalent (>5 µm long fibre) concentrations, either by the authors of the original papers or by the authors of the meta-analyses. Due to limited space some columns have been omitted from the summary table, the references are essentially the same as in the HD and BC papers.

10. Table 2 is organised by exposure to asbestos type in order of chrysotile, amosite, crocidolite and mixed exposure. It can be seen that chrysotile exposures are invariably associated with some amphibole exposure. These are of two types:

- naturally occurring impurity of amphibole asbestos (usually <1%);
- small-scale use of a commercial amosite or crocidolite fibre at the facility (up to a few percent in a limited area of the plant);
- higher use of imported amphibole asbestos types with chrysotile are classed as mixed exposures and appear at the end of the table.

11. The year of operation and the recruitment of the cohort are given in brackets. Usually the brackets denote the period at work, so it is quite possible for a worker to have started work some 20 or 30 years before the cohort period. However, some cohorts are recruited under different conditions e.g. born between 1891- 1920. The year to which the epidemiology had been followed-up (FU) is also given. The cohort recruitment means that some workers were exposed to asbestos before 1920 when it was unlikely that there was any dust control and so much higher airborne dust concentrations.

12. Date of first air monitoring is an important marker for when there is some knowledge of the airborne concentration and should be viewed alongside the period when the cohort was exposed to asbestos. The method of monitoring and when it was used is also given.

**Table 2: Summary of exposure periods and the airborne fibre concentration in the quantitative cohort studies**

Chrysotile exposed					Airborne concentrations by exposure phase/date (f/ml)		
Study cohort	Asbestos types	Exposure Period (cohort study)	Exposure monitoring started and method	Process type	Early	Middle	Late
Quebec mines and mills	Chrysotile + <1% tremolite	Pre 1910 – (Born 1891-1920) FU 1992	1948 MI  Mid 1960s PCM	Year Overall average	1948 225		1968 30
Quebec factory	Chrysotile + <1% tremolite + crocidolite	Pre 1910 – (Born 1891-1920) FU to 1992	1944 MI		Extracted from data set above		Extracted from data set above
Balangero Mine and mill	Chrysotile + 0.5% Balengeroite	1913 – (1946-1987) FU to 1990	1969 PCM	Year / Reconstruction Drilling Crushing Fibre separation Bagging by hand Bagging automatic	1913-1950 37 ± 10 23 ± 2 40 50 ± 5	1951-1960 36 ± 17 25 36 ± 5 57 ± 4 30 ± 5	1961-1970 14 ± 10 14 ± 7 21 ± 3 - 20 ± 5
Connecticut friction products	Chrysotile only until 1957 +anthophyllite + crocidolite 1964	1913 – dry process ended in 1970 (1938 – 1958)	4 studies in 1930's MI  1970 PCM	Year / estimated Pulverising waste Sheet packing: Fibre room Mixing Other	1930-1939  18 40 7	1940-1959  9 27 5	1960-1970  3 18 3

		FU to 1977		Millboard wet Wire mould brake linings: Mixing Other Brake finish/hot press: Dry mould mix grinding Ring finish	6 9  25 3 72 13 17	4 6  8 2 26 8 9	1.5 1.5  3 1 15 3 3
UK Friction Product manufacture	Chrysotile + Very minor crocidolite before 1945	1900- (1941-1977) FU 1975	Only from 1967 onwards PCM	General levels Grinding and preparation	Pre- 1930 20	1931-1950 5  20	1960 –1970 <5 After 1970 <0.5
New Orleans Asbestos cement plant1	Chrysotile only to 1940 + Amosite 1960s + crocidolite 1960 – 70s	1942 –  (FU to 1981)	1950s MI	Year  mean	1940-1949  10.0	1950-1959  7.2	1960-1969  1.3
New Orleans Asbestos cement plant 2A	Chrysotile only	1937 -	1950s MI	Year  mean	1940-1949 8.0	1950-1959 9.1	1960-1969 3.1
New Orleans Asbestos cement plant 2B, pipe only.	Chrysotile + crocidolite from 1946	1937 -	1950s MI	Year  mean	1940-1949 8.0	1950-1959 9.1	1960-1969 3.1
South Carolina Textile	Chrysotile + Minor Crocidolite	1895 - 1975  (1940 –65)	1930-1971 MI	Year Average Range	1930 –1940 >10 (3 –78)	1940 – 1950 5-10 (3 –17)	1950 – 1970

Manufacture	1950 –72 + minor amosite in late 50s	FU to 1990	1971-1975 PCM	(Dement)			
South Carolina Textile Manufacture	As above  (Mc Donald)	1895 – 1977  (WB 1938 – 58)  FU to 1990)	As above	Year Preparation Carding Spinning Winding Twisting Weaving Finishing/inspection	1930 –1940 21 19 21 17 37 13 8	1940 – 1950 12 9 12 10 24 9 6	1950 – 1970 6 6 9 6 6 7 3
UK Friction Product manufacture	Chrysotile + Very minor crocidolite before 1945	1900- (1941-1977) FU 1975	Only from 1967 onwards PCM	General levels Grinding and preparation	Pre- 1930 20	1931-1950 5  20	1960 –1970 <5 After 1970 <0.5
Rochdale Textile	Chrysotile + 5% crocidolite 1932-68	1897 - 1974 (1933-1974) FU 1983	1951 TP at 23 fixed points. PCM 1960 onwards mostly fixed points	Examples of areas Unloading stacking Harridge mill Carding & chopping Roving, spinning Spinning, beaming Other	1933-1951  No measurements but 1951-55 levels assigned	1951-59 28 28 16 9 9 2.5	1960- 1974 20 20 15 7.5 7.5 2.5
Amphibole exposure							
Wittenoom mine and mill	Crocidolite	1942-1966 (men 1943- 1966) FU to	1966 PCM	Mined and mill mean Environmental mean		17.8 f/ml 0.8 f/ml	

Massachusetts Cigarette paper	Crocidolite	1951-57 (1933) FU	1952 MI	Mean	6 – 60 f/ml		
Patterson Insulation manufacture	Amosite	1941-1954 (men 1941-1945) FU 1982	None taken	ESTIMATED, NO SAMPLING: Mean from 14 – 75. Individual process: Disintegrator 120, pulverizer 110, bag opening 100, carding 90, weaving, roving, block production 60, Others 50. Overall Median assumed to be 50.			
Tyler, Texas Insulation manufacture	Amosite	1954-1972 (men 1954 – 72) FU to 1993	1967, 1970, 1971, by PCM	Average 45 f/ml range 15.9 – 91.4 f/ml with a lower but similar pattern to the estimates for Patterson. Higher values between 1954-67, same as for Patterson.			
South African miners and millers	Amosite	1910- (1945 –55)	1945 –65 K 1965- 75 TP 1970 - PCM	Overall estimated average from mines	1945	1960	1970
	Crocidolite	FU to 1980		Amosite surface	150	56	40
				Amosite underground	14	6	4
				Crocidolite surface	30 –160	10 – 50	8 – 30
				Crocid underground	2 - 60	2 - 6	2 - 6
Libby Mine and mill	Tremolite and other amphiboles	1935 (pre-1970) FU to 1981	1950-65 MI 1965 –69 MI 1967 –82 PCM	HIGH ESTIMATES	1950-1963	1964 –74	>1974 MF
				Mine drilling	23	14	0.6
				Mine other etc.	2	2	2.6
				Bus ride	1	1	1.2
				Dry mill sweeping	182	30	Closed
				Dry mill	168	27	Closed
				Old&new wet mill	7	7	0.6
				Skip area	88	17	0.6
Ore loading	83	5	0.2				
River dock	117	12	0.5				

Mixed exposures							
Cement manufacture Ontario factory Board, pipe and insulation	Chrysotile board 1955 –70 Chrysotile + 20% crocidolite pipe 1948 –70? Insulation 1960 –70.	1948 - 70 (Pre 1960) FU 1981	MI in 1949, 1956, 1956,1957, every 2 years after 1960  PCM 1969 onwards	Mixing Forming Lathe ops.	1949 40 16 8	1969 20 8 4	1979 0.2 0.5 0.3
Austrian asbestos cement manufacture	Chrysotile 1895- Crocidolite 1920 – 1977 Amosite 1970-86	(1950 –1981)	1965 –75 by Konimeter  1975 onwards PCM		1945 -1965 No values given high production, dusty open mills, jute sacks	1969-1975 No values given Extraction of dust “sufficient” from 1969	1975 - No values given  Low new dust control system installed in 1975 before PCM measurements
Swedish cement plant	Chrysotile + 4% Crocidolite until 1966 + <18% amosite in 1950s	1907-1978 (1907–1977)  FU1986	1956-69 MI  1969 – 1978 PCM	Milling Mixing Machine line Sawing Grinding Others	1956-65 MI 6.0 3.0 1.5 4.0 6.3 <2	1969 PCM 5 0.3 0.3 1.7	1975 PCM 1.7 1.3 0.9 1.2 1.5
Belgium cement plant	Chrysotile + 8% crocidolite + 2% amosite	1928 - (1963 –1977) FU 1977	1970 –76 PCM	Raw asbestos handling Finishing processes Moulding processes	Estimated 1928 100 24 16	-	1970-76 10 2.4 1.6

				Offices + outside	0.4		0.4
Johns – Manville retirees Various products.	Chrysotile textile and board. Crocidolite pipes.	FU 1981	1955 MI				
US insulators Various insulation products	Various insulation products Chrysotile. Amosite and crocidolite	FU1986	No monitoring				
KEY	* Authors deny use of crocidolite but found in lung samples.	(at work) FU=follow up WB= worked before	K= Konimeter MI=Midget Impinger. TP= Thermal Precipitator. PCM= phase contrast microscopy				



13. Several cohorts had no airborne monitoring data at all (e.g. Patterson and the US insulators) and rely on estimates of working conditions/exposures from elsewhere (e.g. Tyler, Texas for Patterson). Many cohorts did not have any airborne measurements carried out until very late when controls were undoubtedly much better (e.g. Tyler, Balangero, Wittenoom, Belgian AC plant, UK friction products) and had to recreate/simulate previous conditions from memory to assess the likely airborne fibre concentrations to which the cohort was exposed.

14. The method of sampling and analysis used is related to the date of first monitoring and the location of the cohort. Many of the early methods of monitoring are problematic to interpret and have a number of shortcomings. The methods in use are summarised in Table 3. All the early impinger sampling methods (e.g. Owen, Konimeters, Greenburgh-Smith (GS) and midget) could not capture efficiently particles below about 1 µm diameter. The standard Thermal precipitator (TP) (Green and Watson, 1935 and Cassella) was much more efficient but reportedly under sampled long fibres (Walton, 1982& 1985) due to the inlet characteristics and the low flow rate, as well as the thermophoretic effect being reduced for larger particles.

15. The performance of the microscope method was the next most important issue. Konimeters used inbuilt microscopes of medium magnification (~x200) but relied on the user pointing them at a suitable nearby light bulb to carry out the count. Other methods use bench mounted light microscopes. Greenburg Smith (1922) and midget impingers collected into a liquid, which was diluted to a known volume and an aliquot placed in a counting cell. The poor capture efficiency below 1 µm and the presence of Brownian motion and a variable focal plane, meant that relatively low powered microscopes were used compared to the thermal precipitator and the Owens counter (e.g. x1000 & x2000).

**Table 3: Summary of sampling/analysis methods used for the cohort studies**

Method	Date first used	Sampling Rate	Time of sampling	Method of analysis/ LOD(µm)	Unit of measurement	Efficiency with TP
Owens jet dust counter	1922	50 (cc)	Instant	LM x1000	Particles p/cc	Low
Konimeters	1919 + various	5 (cc)	Instant	LM x150-220 dark field	Particles p/cc	5% at 0.4 µm 10% at 0.8 µm 25% at >1.6µm
GS impingers & midget impingers	1922 1937	28 l/min 2.8 l/min	Variable counted in liquid	In liquid x 100-200 (0.75 -1)	Particles p/cubic foot	Low cannot be used for particles <1 µm
Thermal precipitator LRTP in UK	1926 & 1935 1961	7 cc/min	Variable but limited	X2000 oil immersion with graticule (0.1)	Particles p/cc Fibres f/cc >7.5 µm long & all (1 µm) >2:1 AR	~ 100% for <5 µm particles reduced capture for >10 µm long fibres

PCM / membrane filter	1965	$\geq 240$ L	Variable usually 4 hours	X500 phase contrast (0.2)	Fibres/cc >5 $\mu\text{m}$ long <3 $\mu\text{m}$ width >3:1 AR	About 75% of TP for PCM of crocidolite
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### ***The PCM index of risk***

16. The membrane filter (MF) phase contrast microscopy (PCM) method has replaced all of the previous measurement methods and partially defined a single index of “regulatory” fibres, for risk assessment purposes (note >5  $\mu\text{m}$  long fibres were first adopted in 1958 for TP counting). This raises a number of important issues, for example:

- How good a measure of risk is the PCM defined fibre count?
- What are the measurement and use limitations of the PCM method?
- How do you convert previous measurement to the PCM index?

17. The PCM index of measurement has only a limited relationship to biological potency of fibres and it has long been argued that it was drawn up too loosely and a more biologically accurate index would be something like particles >20  $\mu\text{m}$  long, <1  $\mu\text{m}$  width and with an aspect ratio of >10:1. However, the current index at least includes these fibres and is far better than the previous indices based on particle number.

18. One important limitation for the PCM counts is that all fibres meeting the size criteria and not just the asbestos fibres will be included in the count. The visibility of fibres is also important and routinely fibres down to about 0.2  $\mu\text{m}$  should be visible but many asbestos fibres can be thinner. The very thin fibres, <0.1  $\mu\text{m}$  width, are thought by some authors (Lipmann) to carry a high proportion of the mesothelioma risk. The PCM index counts only a few percent of the fibres (i.e. particles of >3:1 aspect ratio) present in the air and some authors argue that fibres of all lengths are carcinogenic. Overall, the PCM count offers a limited but partly biologically relevant index of the fibres present in the air and does not change the fibre size distribution to which the person has been exposed. However, the PCM method and the index itself are subject to random and systematic counting errors and the latter have changed over time. This has important repercussions when considering how to extrapolate the risk models and to calculate risk based on modern day PCM measurements.

### ***Limitations and errors of PCM counts***

19. Fibre counting has poor precision due to the random distribution of fibres on the filter. At low fibre counts e.g. 15 fibres the 95% confidence interval for a Poisson distribution is between 8.4 – 24.7 (a factor of 3) and at counts of 100 fibres the 95% confidence interval is 81 – 121.6. This is without any subject errors from the counter or equipment differences. For PCM fibre counts there is also a background count of fibres on the blank filter. All these factors combined, mean that the PCM method has limitations for evaluation of low fibre concentrations (as would be expected from

environmental samples) and usually for regulatory purposes the limit of quantification is set at ~ 20 fibres counted (e.g. clearance sampling – see HSG 248).

20. An important limitation for historic measurements is the upper limit to which PCM measurements can be reliably used. Based on a 240 L, four hour time-weighted average (TWA), the equivalent volume of about 500 ml of air is examined during the PCM count. Experience has shown that even with the modern form of the PCM analysis substantial undercounting takes place above loadings of 1200 f/mm<sup>2</sup>. This means the upper limit of the method is ~ 1.8 f/ml. When the PCM method was first introduced in the US, The new Occupational Safety and Health Administration (OSHA) set an air concentration limit of 12 f/ml and many processes may have been higher. This suggests that there may have been substantial low bias due to the undercounting of the fibre concentration, even if shorter samples were taken. It is also quite possible that higher concentrations were so overloaded that no count was attempted. Therefore in some cohorts there may have been a systematic underestimate of the peak fibre concentrations when PCM fibre counting was introduced. These biases will produce a lower gradient to the dose-response which in turn will over predict the risk at low levels.

21. There are a number of documented factors which lead to undercounting and poor precision in the early PCM counts:

- Whole field counting without a graticule;
- Use of a mounting method, which did not collapse the filter requiring the microscopes to rack through focus to find fibres;
- The absence of halogen high illumination sources for optical microscopes;
- No counting rules for complex bundles and fibre structures;
- Not counting fibres attached to > 3 µm particles;
- No aids to help size the fibre length and width accurately;
- No check that phase contrast optics and the microscope were adequate;
- No performance check with a test slide;
- No training of microscopes or performance testing.

22. The above lead to large differences (~ factor of 10) between laboratories (Walton, 1982) and extensive work and improvements have been undertaken over the last 40 years. Therefore a modern day measurement of the PCM fibre index is likely to be several times higher than the PCM measurements made in the late 60s, when the conversion factors from the historic measurements were made (e.g. Ayer et al., 1965; Dagbert (1976); Gibbs and LaChance (1972); Lynch et al. (1970)). It should also be remembered that conversions were for static measurements and personal samples would have been two or more times higher on average. Therefore there is significant possibility of a systematic under-estimation of airborne fibre concentrations of the cohorts, which would result in over-estimation of the risk when extrapolating to lower exposures.

## Conversion of previous measurement

23. At the time the PCM method was introduced a number of conversion studies were undertaken with the previously used methods. These were often found to be very variable and process dependent. This was partly due to many of the conversions being from the GS and midget impinger methods used in the US, which counted all visible particles in units of million particles per cubic foot (mppcf). The particle counting methods suffered from the same variability that has been described for the PCM and a factor of 10 difference would not have been uncommon between counters. Given the poor precision of the two methods only large numbers of samples are likely to give an approximate near to the mean. Work carried out by Lynch et al., (1970) derived the following relationships with the early form of the PCM count, see in Table 4. Given the percentage of asbestos to matrix material, they had some correlation between the amount of asbestos in the product and the fibre concentration. Side-by-side sampling of impingers and PCM samples in the Canadian mines and mills produced an extremely wide scatter for individual samples which when plotted on a log-log scale gave a correlation coefficient of 0.437.

**Table 4: Examples of conversion factors between and the early form of PCM.**

Product	Percentage asbestos in product	Sample pairs	Fibre to particle ratio in f/ml: 1 mppcf	Reference
Textile	70- 100%	500	5.9	Walton, (1985)
Friction	30- 50%	200	2.2	Walton, (1985)
Asbestos cement pipe	10-15%	100	1.9	Walton, (1985)
Chrysotile mines and mills	1-5%	623	$10.97^{0.68}$	Dagbert, (1976)

## Air concentration measurements before 1960's

24. It is clear from:

- the low collection efficiency of fine fibres by impingers,
- the counting of particles rather than fibres,
- the poor counting precision and the range of individual conversion factors;

that there is considerable uncertainty about the airborne concentrations before 1960, when most of the cohorts were exposed. Some papers claimed very high levels airborne asbestos were present and in industrial environment when dry processing and handling took place and levels were high and often above a 100f/ml into the 1950's (Liddell, 1985).

25. Ideally, to test these inferences we need some reliable sampling information similar to the modern PCM count from 50 or more years ago. Fortunately, some data taken by the UK factory inspectorate in the 1930's does exist and can even be related back to the first published airborne levels of asbestos particle concentrations in UK asbestos factories, taken during the 1928-29 surveys by Merewether. The initial surveys were expressed in terms of relative dustiness in the Merrewether and Price report (1930) and also published in the scientific press (Merrewether, 1930). This early survey gave results of particle counts from a 1928-29 survey was carried out using an Owens jet dust counter (Owen, 1922). Where 51 samples from 8 factories were collected and gave a range of values from 506 p/cc for braiding to 6324 p/cc for opening the asbestos bales and shovelling into a box. Many of the processes sampled were co-located with other processes, which with the short sampling time, was recognised to provide only a limited reference data.

26. Mr Kenneth Goodall of the Factory Inspectorate, also took samples in an crocidolite asbestos textile factory (J.W. Roberts at Armley, Leeds) on the 20th July 1938 (Table 5). The Goodhall samples were taken in the same factory and spinning area that had been surveyed in 1928-29 by Merrewether. Both the Goodall and Watson samples were taken with a thermal precipator and analysed by x2000 oil immersion microscopy. Not only has this method been shown to be equivalent to the modern PCM but gave substantially higher counts when compared using a similar textile grade crocidolite to that used in the factory (Burdett, 1998). Other important factors were that a counting and sizing graticule was used and organic fibres were removed from the sample prior to counting. Both personal and area samples were taken, the samples were taken in the spinning area of the factory that was sampled in the 1928-29 study used by Merrewether to establish the “dust datum” that formed a de facto “control limit” for asbestos up until the 1960s.

**Table 5: Result from the survey in the spinning room at a crocidolite textile factory 1938**

Job type	type	All size fibres	>5 um long fibres	All particulates	Conversion
		f/ml	f/ml	p/cc	mppcf
Spinner Flyer - personal	Personal	165	41	230	6.57
Single thread - static	static	195	25	423	12.08
Spinner Fly - personal	personal	335	50	635	18.14
Single thread + cotton - static	static	300	39	775	22.14
Spinner Fly - personal	personal	410	78	800	22.8
Double thread - static	static	260	39	560	16

27. Goodall counted all particles, all fibres (assumed a ~2:1 to 3:1 aspect ratio) and sized the fibres by length and width. Length categories included fibres >5, >10 and >20µm long. A count in terms of fibre length was undertaken as they were thought by Merewether (1938) to be of the most biological relevance, as they would be too large for a macrophage to engulf and clear from the lung. The values were from a single days measurement when the doors and 12 large hopper windows were open to provide ventilation. The conditions on that day would have given significantly lower

concentrations than would be expected at other times of the year, where reduced ventilation would lead to a greater build-up of fibres.

28. These important measurements using a method of superior resolution to the modern PCM, showed that the datum to which factory owners were asked to control to, was likely to be equivalent to average personal airborne concentrations in the range of 20 - 50 f/ml. Some processes were considerably more dusty than spinning and some airborne concentrations in the textile industry would have been around 100 f/ml before further control was introduced. It was likely that levels began to drop in the 1950's to give a near three-order of magnitude reduction to the airborne control limit of today (0.1 f/ml). Any estimate of cumulative exposure is therefore very sensitive to where and when the person worked. It is likely that other asbestos industries followed a similar pattern although the air concentrations would be reduced if the asbestos was added to a matrix or wet processed.

29. Although some epidemiological studies took great efforts to estimate individual and job specific exposures based on conversions of particle counts, others did not. Therefore the estimated air concentrations in Table 2 calculated for the individual cohorts, need to be reviewed for the presence of systematic errors, and their relationship to the modern day PCM method. There also need for careful appraisal of the likely effects on the predicted risks when significant extrapolation of the risk models is undertaken, using modern PCM fibre concentrations as the basis for the cumulative exposure/dose.

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