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HEALTH & SAFETY LABORATORY

Investigation Into The Effective Laundering Of Towels and Coveralls Used For Asbestos Work.

HSL/2002/22

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Summary

Objectives

The aims of this project were to:

1. Investigate the contamination of towels and coveralls used in asbestos removal hygiene units.

2. Investigate the effectiveness of the laundering process when decontaminating these towels and coveralls.

3. Investigate the laundries used to launder asbestos contaminated towels, particularly with regards to the safe handling of asbestos contaminated materials.

Main Findings

1. A telephone survey and follow up investigation showed that very few commercial laundries will launder asbestos contaminated towels / clothing. This has resulted in more employers making their own laundering arrangements. Safety standards range from no precautions (assumption is that towels are not contaminated) to the operation of purpose built laundries to the same standards as an asbestos removal enclosure.

2. Asbestos contamination was found on towels used by asbestos workers. This suggests that the towels became contaminated through the drying process and/or general misuse and that effective decontamination procedures were not being followed. Amosite asbestos fibre densities of up to 154 f mm^{-2} were found on towels, intercepted (with agreement of the laundry) before laundering, when sampled using micro vacuuming techniques. However, mechanical agitation in a rotating drum dustiness tester produced airborne fibre concentrations of less than 0.01 f ml^{-1}. These fibre levels were calculated not to be significant when workplace conditions were taken into account.

3. Residual asbestos was found on towels after laundering. Although there was some evidence to indicate that asbestos fibre densities on heavily contaminated towels were reduced, the fibre levels on lightly contaminated towels appeared to be little changed by laundering. Airborne fibre levels <u>inside</u> the rotating drum dustiness tester were generally very low (< 0.01 f ml) but two towels, whose pre-laundering contamination levels were unknown, produced higher airborne fibre levels, 0.17 f ml^{-1} and 0.21 f ml^{-1} but the same comments regarding workplace conditions apply as in 2.

4. Laundering was effective in removing asbestos from coveralls. Little or no evidence of asbestos was found after asbestos contaminated coveralls were laundered.

5. The standards of cleanliness and the precautions taken with regards to safety (asbestos) at the two laundries visited were found to be very high. Both laundries were purpose built for dealing with asbestos contaminated laundry. They operated under negative pressure with the extracted air being HEPA filtered and appropriate precautions were taken when handling towels and clothing prior to laundering. These items were regarded as being contaminated with asbestos.

6. A test simulating the handling of freshly laundered towels in a laundry showed that low levels of airborne fibres could be released when handling freshly laundered towels (< 0.05 f ml^{-1} from forty towels over an eighteen minute period). Again, these fibre levels were calculated not to be significant when workplace conditions were taken into account.

Main Recommendations

1. Employers should ensure that asbestos workers decontaminate themselves thoroughly and properly, by taking sufficient time, care and attention, so that the decontamination process is effective.

2. On returning via the dirty end of the hygiene unit all workers should shower thoroughly and start the drying process in the shower section before returning to the clean end of the hygiene unit. Any towel taken into the shower section should be treated as contaminated and be either disposed of as asbestos waste, or bagged up for washing at a laundry which has the facilities and expertise to launder asbestos contaminated items.

3. Coveralls used during asbestos removal or renovation work should be treated as contaminated with asbestos and removed in the dirty end of the hygiene unit. These contaminated coveralls must either be disposed of as asbestos waste or bagged up for washing at a laundry which has the facilities and expertise to launder asbestos contaminated items.

4. Contaminated towels should be bagged and laundered separately to contaminated coveralls.

5. Laundries dealing with asbestos contaminated items should assess the potential risks arising from this work (both pre and post laundering) and take the necessary precautions to prevent or minimise their employees' exposure to asbestos. These precautions should include good mechanical air extraction (negative pressure); limited access: a clearly defined lockable room(s) to which only designated staff are allowed access); regular air monitoring; and high hygiene standards).

Contents

1. INTRODUCTION

The Health and Safety at Work etc. Act [1974] requires an employer to provide a safe workplace. Work with asbestos is covered by its own set of regulations - the Control of Asbestos at Work Regulations (CAWR) 1987 and currently supported by two approved codes of practice (ACoP). These require that when asbestos containing materials are removed or disturbed precautions have to be taken to prevent or minimise exposure to airborne asbestos fibre releases. In effect this means that to minimise the risk of exposure to airborne asbestos, much work involving the disturbance of asbestos requires the use of dust suppression removal techniques and the use of an enclosure under negative pressure, the workers are required to use respiratory protection and protective clothing (either reusable or disposable coveralls), and for the workers to thoroughly decontaminate, including showering, on exiting the negative pressure enclosure. These requirements also apply to any other persons (for example HSE inspectors) going into the prescribed work area.

Showering is carried out in the central compartment of a three stage decontamination or hygiene unit. One end of the unit is classified as the 'dirty end' and here the worker leaves any contaminated clothing. This contaminated clothing must be bagged and either disposed of as asbestos contaminated waste or cleaned at a laundry that takes special precautions when handling asbestos contaminated materials.

The worker then showers and decontaminates his respirator in the shower unit before donning his normal work / street clothes in the 'clean end' of the hygiene unit. In some cases the towel is taken into the shower compartment and in others the workers dry themselves in the 'clean end'. In theory, having showered, the worker should be free from asbestos contamination and the towels used to dry the workers, should not become contaminated. In practice this has been found not to be the case, as towels may also be used to dry 'decontaminated' respiratory equipment and for a variety of other functions, becoming contaminated in the process.

Current HSE advice to removal contractors is that towels taken into the shower unit should be treated as contaminated and not returned to the 'clean end' of the hygiene unit. If the worker transits to the 'clean end' and dries himself in there, the towel can then be considered to be uncontaminated (by asbestos).

HSE commissioned this study into the state of towels used in asbestos removal hygiene units to determine:

- whether towels used in hygiene units (for use with asbestos) are contaminated
- whether towels and coveralls are effectively decontaminated by the current laundering procedures.

Minerals and Fibres Section HSL approached the study by:

w A literature search to investigate what previous work had been carried out in this area.

w A telephone survey to determine how asbestos removal companies handle laundering of towels and coveralls.

w Laboratory experiments to examine whether towels become contaminated with asbestos both before and after laundering. Similar experiments were to be carried out on coveralls.

2. LITERATURE SEARCH

A literature search indicated very little or no work had been carried out in this area. A paper by Grosse [1998] showed that about ten percent of the asbestos (chrysotile) fibres from low level contaminated textiles remained after laundering. It was however, noted that the continuous fibrillation of the asbestos fibres during laundering reduced the length of many of these fibres so that they were below the lengths considered hazardous to health. An unpublished reference in internal HSE files referred to work which examined methods of detecting asbestos fibres on textiles. This report concluded that none of the asbestos identification methods employed enabled quantification of asbestos contamination to be carried out. The report concluded that from qualitative examinations laundering of contaminated clothing was effective and that cross contamination was not a problem. It did however, include a rider stating that "Because of the qualitative nature of the test method it is not possible to give an absolute statement about the effectiveness of the laundering process".

A technical circular [1998] put out by the Fabric Care Association (FCRA) made a series of recommendations to those of their members who handle asbestos contaminated clothing. The recommendations are summarised here.

- There should be liaison between the contractor and the laundry to ensure that the laundry knows that the clothing is to be treated as contaminated.
- The laundry should be received in a sealed and labelled water soluble bag, protected against tearing by an impervious outer packing, and clearly labelled: 'Asbestos contaminated material'.
- On reception at the laundry the bags should be segregated from other work (laundry) and the outer packing removed. Laundry in damaged or non soluble bags should be returned to the customer.
- Laundry items in the sealed water soluble bag should be placed in the washing machine. Continuous batch type machines should not be used.
- Water used for washing must not be reused. An efficient pre-wash to dissolve the bags is important and a three wash process is recommended.
- A tumble drier should be reserved for this work. It should extract to the atmosphere outside the building and away from ventilation air intakes.
- Lint screens (on tumble dryers) should be cleaned before drying asbestos loads and again after drying. Precautions against asbestos exposure should be taken and waste from the lint screens disposed of as asbestos waste.

- The tumble drier should be underloaded during drying, it should be followed by a 'cool down' stage and finishing, if required, should not involve an air blowing cycle.

There is also anecdotal evidence from companies involved in the asbestos removal industry which suggests that laundering of towels does not fully decontaminate them.

3. TELEPHONE SURVEY

A telephone survey of eighteen asbestos removal companies questioning how they launder towels used in hygiene units, was carried out. The findings from this survey are summarised here.

- Some asbestos removal contractors (7 out of 18 questioned) use disposable towels to avoid the problems of laundering. [FOD's current practice is to use cotton towels and to dispose of them as contaminated waste].
- Most companies (8 out of 11 questioned) who launder towels from hygiene units (used for asbestos) treat these towels as contaminated but some claim: "the towels are used to dry workers after they have showered and as the workers are ‘clean’ and the towels never go into the contaminated areas of the hygiene unit they are not contaminated”.
- Several companies (5 out of 18 companies), including some of the larger ones have their own laundries. Some of the companies that have their own laundries treat the towels as contaminated but others regarded them as uncontaminated. A follow up to the initial survey found a wide range of standards. At one small company, the office manager did the laundry in a domestic washing machine in a room adjacent to her office; without taking any precautions. At the other end of the range a large asbestos removal company had its own purposely designed laundry taking every possible precaution, including HEPA filtering extracted air and waste water.
- A small number of commercial laundries said that although they would launder contaminated towels they only took such laundry from known regular customers, for example the fire brigade. Generally they needed advance warning and although they laundered the 'contaminated' laundry separately they used their normal laundering facilities, possibly with an extra wash or rinse. (3 commercial laundries which were prepared to launder asbestos contaminated laundry were identified)
- A small number of companies (2 out of 18 questioned) expected the workers to launder their own towels.
- From the initial survey and from further follow up enquiries it was apparent that commercial laundries were becoming increasingly reluctant to launder asbestos contaminated laundry (including towels) and that asbestos removal companies were being forced into using either disposable towels or laundering towels (and contaminated clothing) themselves.

During the survey an advert for a new type of welfare unit was discovered. Facilities available with these units included a washing machine, tumble drier and a range of other welfare facilities including a refrigerator, sink, hob and sockets for an electric kettle. The clean end of the hygiene unit doubles as a mess room.

This telephone survey was a snapshot of the situation at the time of the survey. Follow up enquiries suggested that, especially with smaller companies, changes occurred quite often.

4. VISITS TO LAUNDRIES

As a preliminary to carrying out laboratory based testing two laundries were visited. One was operated by a large asbestos removal company and the other by the asbestos removal unit of a metropolitan council.

4.1. Laundry A:

This laundry was selected because the telephone survey indicated that it was 'state of the art' and appeared to be one of the laundries making the greatest efforts to reduce asbestos fibre releases.

This operation was in a 10m x 10m room designated as the laundry and was in the main area office / depot buildings. The door was clearly labelled with a 'Danger Asbestos' warning label and access was only permitted by persons wearing protective clothing (coveralls, over shoes and disposable mask). Generally the only person to go into the room was the part-time laundry man. Inside the laundry were two industrial electrolux 75 washing machines and a tumble drier. The waste water was filtered, as was the extracted air (HEPA filter). These filters were regularly serviced by a specialist company but it was planned to introduce a clear plastic viewing panel so the state of the filters could be monitored. The room was kept at negative pressure to ensure that any asbestos fibre releases were contained within it. Airborne fibre levels, from what was described as a 'worst case scenario' (laundering contaminated reusable coveralls, were reported as being 0.2 f/ml.) [1]

The laundry was only used for in-house laundering of towels and coveralls, contaminated articles were not taken in from other external sources. Contaminated towels and coveralls were double bagged (water soluble inner bag, clear plastic [danger asbestos marking] outer bag) in the dirty end of the hygiene unit and delivered to the laundry by company employees. At the laundry the outer bags are removed and the towels / coveralls, still sealed in the inner bag, put into the washing machine for a standard washing cycle at 95 °C using an industrial non biological detergent. The towels are then dried in a tumble drier. It was claimed that reusable coveralls were only used when the probable contamination levels were low (asbestos tiles, board, asbestos cement etc.) and not used when, for example, loose or friable insulation was being removed. Consequently, any reusable coveralls laundered were unlikely to be excessively dirty. Also coveralls were always laundered separately from towels. The laundry was tiled making it easy to wash down.

It was agreed with the laundry manager that a bag of towels would be diverted to HSL so that they could be inspected and analysed for asbestos contamination.

[1] These are not HSL values and exactly what the procedures and conditions under which they were produced is unknown.

4.2. Laundry B:

HSL were put in contact with this laundry by a local HSE inspector who had recently inspected it and found that it operated in a safe and satisfactory manner.

This laundry was operated principally for the in-house laundering of towels and coveralls used in asbestos removal work. The one exception was a contract for the laundering of fire fighters' uniforms. Although some of these uniforms may have been subject to asbestos contamination the majority were soiled by a range of non asbestos materials. All the laundered items, including those from the fire brigade were collected and delivered to the laundry reception area by company employees.

A plan of the laundry is shown as figure 2. The whole laundry complex is kept under negative pressure (3,000 cfm), activated by a switch outside the complex. Access to the 'clean' areas is generally restricted to trained personnel and supervisors and only eight trained personnel wearing appropriate protective clothing (masks, coveralls) are allowed into the restricted 'dirty' areas. Anyone entering these 'diry' areas is required to return through a three stage airlock and to shower.

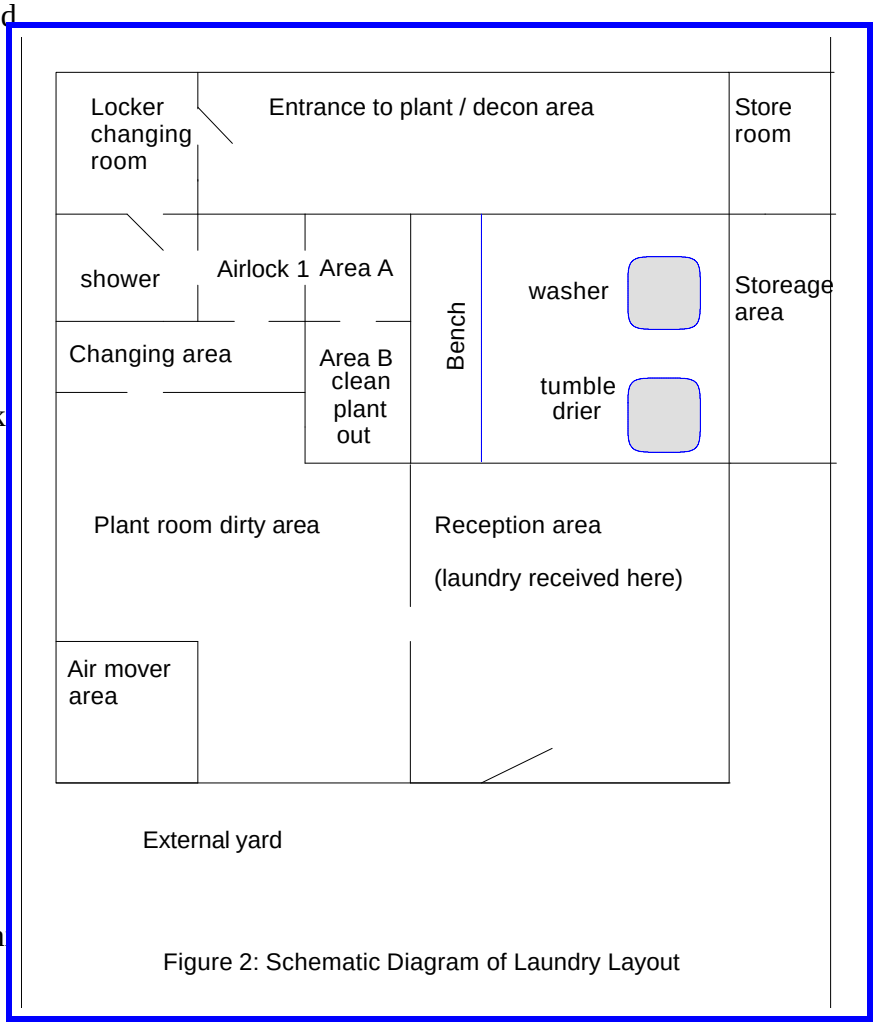

Figure 2: Schematic Diagram of Laundry Layout

The procedure is more complex than that in 4.1. Coveralls are treated as contaminated and are received in water soluble bags (clear marked as asbestos waste) but towels are not considered as contaminated ["the workers shower and transit to the 'clean end' of the hygiene un where they dry themselves: the towels never leave the 'clean end' and are not contaminated"] and are received in unmarked plastic sacks. In the 'dirty' section of the reception area the towels are removed from the plastic transit bags and repackaged into water soluble bags before being passed into the washer area. Any outer packaging (outer sacks etc.) is removed from bagged coveralls which are also passed (in their water soluble bags) to the

washer room. Coveralls, towels and fire-fighters' uniforms are never mixed and are always washed separately.

Washing is carried out in a large industrial washer using a standard wash cycle. The washed items are then transferred to a large industrial tumble drier and dried for an appropriate time. This washer room is designated a clean area and clean towels etc. are stored in it. On the day of the visit the room, washer and tumble drier appeared to be clean. Surface samples were collected from the lint collector (tumble drier), the tumble drier, the washer and adjacent bench surface and analysed for the presence of asbestos. Although the lint collector was clean, one small clump of fibre was found and taken for analysis. Asbestos was not found in any of these samples when examined using MDHS 77 techniques.

The waste water from the washer is not currently filtered but steps are being taken to include a filter, as requested by the HSE inspector. The air extracted from the complex via the negative pressure unit is filtered using a HEPA filter but the air extracted from the tumble drier is vented unfiltered to atmosphere on the roof of the building. We had some discussion as to whether adding a HEPA filter would be effective. [Although the HEPA filter efficiency should not be compromised by warm wet air, the back pressure, if it clogs up, could lead to leakage back into the washer room, through the seals in the tumble drier door].

Two laundered towels and two laundered coveralls were taken for examination for asbestos contamination.

5. LABORATORY INVESTIGATIONS

The intention was to carry out laboratory based investigations into the contamination levels on towels intercepted on their way to the laundry from asbestos removal hygiene units and also to re-examine these towels after laundering.

5.1. Fibre Sampling:

The detection and analysis of asbestos fibres on textiles is difficult. Grosse [1998] states: "The direct counting of asbestos fibres on textiles is practically impossible. It succeeds with microscopic methods only by the chance finding of a few asbestos fibres in an oversized number of textile fibres". He recommends the mechanical removal of the fibres from the textile before attempting to carry out any analysis.

As reported by Grosse it was impossible to detect asbestos fibres directly on the textiles but two methods of non destructive sampling used extensively at HSL for recovering asbestos fibres from a wide range of materials, including textiles were effective as a means of sampling the textiles (towels / coveralls) for asbestos fibres.

- *Micro Vacuuming*: a 6 mm (¼ inch) internal diameter plastic tube, cut at 45°, is attached to the cap of a standard conducting plastic cowl (3 cm x 25 mm). Air is drawn through the plastic tube using a sampling pump operating at a known flow rate (l min^{-1}) and the cut end of the tubing

wiped over the contaminated surface. Loose debris is vacuumed up from the surface and collected on a membrane filter. This material can then be analysed for asbestos fibres.

- *Rotating drum dustiness tester*: the material to be sampled is placed in a ~ 400 mm long, by 300 mm diameter steel drum which is rotated about its longitudinal axis at 6 hertz (rev min^{-1}). On the inside of the drum are a series of six 1 cm vanes on which the material being tested is lifted and tumbled, subjecting the material under test to repeatable mechanical agitation. A pump (outside the drum) is used to extract air at 10 litres per minute (~ 20 air changes per hour) through a membrane filter, thus sampling airborne debris released from the test material. Some standardisation of the micro vacuuming method can be achieved by sampling from similar areas but the method is difficult to interpret, as the contamination of the towels is unlikely to be uniform and the sampling variability may be large. The rotating drum techniques enables samples from the whole towel to be collected, so they are likely to be representative of the contamination as a whole. Also by sampling for similar time periods, (same volume of air sampled, similar towels and the same degree of agitation) contamination levels may be compared. It should however, be noted that although the rotating drum results are reported as airborne fibre units (f ml^{-1}) these concentrations reflect the very limited air volume (~ 0.03 m^3) of the drum. If, for example, the same number of asbestos fibres were released into the much larger volume of a small modular shower unit (volume ~ $2m^3$) they would result in an airborne asbestos fibre concentration at least 65 times less than those found in the drum.

  The drum was cleaned and tested between each run.

5.2. Analysis for asbestos:

The standard method of determining airborne asbestos concentrations from samples collected on membrane filters is by phase contrast optical microscope (PCM) techniques using the method described in MDHS 39/4. This is a non specific technique and, samples collected from textiles will include large numbers of non asbestos textile fibres which will fulfil the MDHS 39/4 counting rules. This problem can be overcome by using fibre discrimination techniques as described in MDHS 87. Textile fibres have a morphology and optical properties quite different to asbestos allowing the analyst to identify and count, only those fibres that have a clear asbestos morphology. This discrimination proved to be reasonably successful in this work, where there were significant differences in the optical properties of the textiles (cotton) and the asbestos (amosite) fibres. However, the analyst is still the arbiter and must make a judgement as to whether an individual fibre is, or is not asbestos. Consequently a proportion of the samples were further analysed using analytical transmission electron microscopy (TEM) techniques, where energy dispersive x-ray (EDX) and selective area electron diffraction (SAD) techniques can be used to determine fibre type. TEM fibre counts using the same MDHS 39/4 counting rules as those for optical PCM counts are referred to as PCM equivalent counts (PCME) and the fibres are referred to as structures (SF) rather than fibres. Although both chrysotile and crocidolite asbestos are often encountered during removal processes, the vast majority of fibres found during these tests were amosite asbestos. It is possible that the occasional chrysotile (or crocidolite) fibre may have been missed during these analyses but both these techniques (MDHS 87 and TEM) should reliably identify all asbestos types.

5.3. Materials Sampled:

A series of tests were carried out on towels (before and after laundering), and coveralls (after laundering). The materials sampled were:

Material	Sampling method
a. New unused towel (HSL)	micro vacuum
b. Laboratory contaminated towel (HSL)	micro vacuum
c. Contaminated towels intercepted on their way to Laundry A (towels A1 - A7)	micro vacuum or rotating drum
d. Towels from a, b and c after laundering at Laundry A.	micro vacuum or rotating drum
e. Towels (B1 and B2) laundered at Laundry B	micro vacuum and rotating drum
f. Coveralls (A1 and A2) laundered at Laundry A	micro vacuum and rotating drum
g. Coveralls (B1 and B2) laundered at Laundry B	micro vacuum and rotating drum

The levels of contamination, if any, for items e, f and g were unknown. Although these items were laundered as asbestos contaminated it is possible that they were used in situations where there was little or no release of asbestos containing material.

6. RESULTS: TOWELS

6.1. Micro Vacuum Sampling: Unlaundered Towels

The results of micro vacuum sampling of unlaundered towels are shown in table 1. The fibre densities (F mm^{-2}) reported are the densities collected on membrane filters and will depend on the area of material (towel) vacuumed, the sampling rate (flow rate) and the uniformity of the contamination (asbestos) on the material sampled. Values from different samples are only comparable if similar areas (at the same flow rate) are sampled. Although the intention was to sample from 30 x 15 cm areas at 2 litre min^{-1} and to compare fibre densities on the towels, it was found that deposition across individual towels was very variable. Furthermore the variability of fibre densities from towels 'uniformly' contaminated in the laboratory (6.1.2) showed that although micro vacuuming was a

useful qualitative method of detecting the presence of asbestos fibres, the variability in asbestos fibre densities on the towels meant that it could not be adopted to give meaningful quantitative data.

6.1.1. Micro Vacuum Sampling: New Unused HSL Towel.

A new unused towel was sampled to determine the limit of detection of the method. When the filter, onto which the fibres were collected, was analysed using MDHS 39/4 techniques the fibre density was found to be 7.6 f mm^{-2}. This indicated that, for this towel, very few textile fibres were released during micro vacuuming. However, as other towels, intercepted on their way to be laundered, may have contained different textiles and these textiles may have been affected by previous washing cycles, this figure may not be representative of all towels.

6.1.2. Micro Vacuum Sampling: Artificially Contaminated Towel.

To investigate the suitability of the technique for the sampling and analysis of asbestos fibres, and in an attempt to obtain standardised measurements, a section of new towel was immersed in a suspension of amosite in water (0.02 % [0.6 g in 3 Litre]). Four samples, using the micro vacuuming techniques, were collected on filters from different sized areas of this towel. Analysis using MDHS 39/4 techniques gave fibre densities of between 485 and 1,967 f mm^{-2} on filters used to collect the micro vacuumed samples. Using the discrimination techniques described earlier, a discrimination count on one sample, HSL/07563/01, indicated that about 80% of the fibres counted were amosite asbestos. This test showed that samples taken from towels contaminated under controlled conditions gave very variable results. Therefore sampling from used towels using micro vacuuming, although a useful qualitative indicator of the presence of asbestos fibres, would be unlikely to give any meaningful quantitative data.

6.1.3. Micro Vacuum Sampling: Ex Hygiene Unit Towels Intercepted on Their Way to Laundry A.

After using PCM discrimination counting techniques asbestos (amosite) fibre densities of between 13 and 154 f mm^{-2} were found and that between 25 % and 91 % of all the fibres collected appeared to be amosite fibres. A TEM count of asbestos fibres only, using the same counting criteria as used under MDHS 39/4 on sample HSL/07840/01 gave a fibre density of 19.1 f mm^{-2}. This was well within the 95 % confidence error range (7 - 25 f mm^{-2}) of the PCM discrimination count (13.1 f mm^{-2}), indicating that the PCM discrimination counts were giving good approximations to the asbestos contamination levels on the towels.

The towels were received in a single bag, suggesting that they were from the same asbestos removal job but this did not guarantee that they were used by workers handling identical materials. Variations in the amount of contamination and the proportion of the fibres that were amosite asbestos would be expected but it is noticeable that the asbestos fibre densities from the intercepted towels were significantly lower than those from the artificially contaminated towel.

Table 1: Ex. Hygiene unit towels: Micro vacuum sample fibre densities.

Sample No	Towel	All fibres[$]	Asbestos fibres	
		PCM fibre density	Discrimination counts[#]:	TEM PCME
		f mm^{-2}	f mm^{-2}	f mm^{-2} [% amosite]
HSL/07563/01	HSL towel contaminated by saturating with a suspension (0.02%) of amosite in water	560.72	436.3	
HSL/07564/01		532.87		
HSL/07565/01		485.72		
HSL/07566/01		1,967.16		
HSL/07785/01	Ex. hygiene unit contaminated towel A1; Laundry A	168.7	154.2	
HSL/07786/01		221.2		
HSL/07789/01		92.56		
HSL/07790/01	New unused HSL towel	7.6		
HSL/07814/01	Ex. hygiene unit contaminated towel A2; Laundry A	81.62	27.6	
HSL/07816/01		78.11		
HSL/07817/01		86.96		
HSL/07818/01		69.89		
HS/0/7839/01	Ex. hygiene unit contaminated towel A3; Laundry A	29.17		
HSL/07840/01		53.03	13.05	19.13 [14 %]
HSL/07842/01		44.41		
HSL/07843/01		34.8		

[#] MDHS 87 techniques were used to differentiate between asbestos and non asbestos fibres: counting was then carried out on fibres (asbestos only) using the MDHS 39/4 counting rules.
$ includes asbestos and non asbestos fibres

6.2. Rotating Drum Sampling of Unlaundered Materials

The results of the rotating drum sampling from unlaundered towels are shown in table 2. If the samples were tumbled for identical lengths of time then the fibre densities and airborne fibre concentrations (within the drum) should be comparable. This should allow comparisons of contamination levels before and after laundering to be made. It was the intention to sample at 10 L min^{-1} for two hours but the high levels of 'fluff' released from some freshly laundered towels necessitated reduced sampling periods (ten minutes).

Before each test, the rotating drum was washed out and samples collected to demonstrate that the drum was free from residual asbestos fibres. PCM fibre densities of <1 f mm^{-2} were measured on these samples, confirming that the drum was free from contamination. These PCM fibre counts include all airborne fibres, not only asbestos fibres, and showed that the airborne fibre densities generated in the clean drum were less than 0.01 f ml^{-1}.

6.2.1. Rotating Drum: New Unused HSL Towel.

When a new unused towel was sampled for two hours a PCM fibre density of 7.95 f mm^{-2} was produced and a second towel sampled in a similar way but for only ten minutes had a PCM discrimination count of 0.64 f mm^{-2}. Both these results were below the 10 f mm^{-2} limit of detection for fibre counting (see 9.2) and although the first value 7.95 f mm^{-2} was more than ten times the

second it included all fibres whereas the second included asbestos fibres only. Both samples indicated that airborne fibre densities inside the rotating drum were less than 0.01 f ml^{-1}.

6.2.2. Rotating Drum : Ex Hygiene Unit Contaminated Towels Intercepted on Their Way to Laundry A.

PCM discrimination counts indicated that asbestos (amosite) fibre densities on the towels ranged from ~5 f mm^{-2} to ~22 f mm^{-2} and that between 4% and 22% of the fibres collected were amosite fibres. Airborne fibre concentrations (inside the drum) were less than 0.01 f ml^{-1}. All these samples were collected by sampling at 10 litre min^{-1} over a two hour sampling period.

TEM PCME fibre counts on the same samples produced similar fibre densities ranging from ~10 f mm^{-2} to ~23 f mm^{-2}. These were within the 95 % confidence range of the comparable PCM discrimination counts.

Airborne fibre concentrations inside the rotating drum, calculated using these TEM PCME fibre counts, were less than 0.01 f ml^{-1}.

Table 2: Ex. Hygiene unit towels: Rotating drum fibre densities.

Sample No	Towel		All fibres[$]		Asbestos fibres			
			PCM fibre density		PCM fibre discrimination density[#].		TEM PCME	
			f mm^{-2}	f ml^{-1}.	f mm^{-2}	f ml^{-1}.	f mm^{-2}	f ml^{-1}.
HSL07849/01	Empty drum		0.66	<0.01				
HSL07850/01	New unused towel		7.95	<0.01				
HSL07928/01					0.64*	<0.01		
HSL07851/01	Ex. Hygiene unit contaminated towel .	A4	52.37	0.02	13.4	<0.01	22.4 (10 %)	0.007
HSL07852/01		A5	99.68	0.02	21.3			
HSL/07860/01		A6	379.19	0.1	8.1	<0.01	10.0 (9%)	0.003
HSL/07861/01	Empty drum		0.32	<0.01				
HSL/07862/01	Ex. Hygiene unit contaminated towel .	A7	124.39	0.04	5.41	<0.01		

* ten minute sample: all other samples were two hour samples
[#] MDHS 87 techniques were used to differentiate between asbestos and non asbestos fibres: counting was then carried out on fibres (asbestos only) using the MDHS 39/4 counting rules.
$ includes asbestos and non asbestos fibres

6.3. Laundered Towels

After sampling was completed the towels from Laundry A were labelled and sent for laundering. A new unused towel and a towel contaminated at HSL were included with the intercepted towels (all these towels would be laundered as a single batch). After laundering these towels were returned to HSL for further sampling using the same micro vacuuming and rotating drum sampling techniques.

Two laundered towels from Laundry B were also subject to the same sampling and analysis techniques.

6.4. Micro Vacuum Sampling:

To try and produce samples that were comparable with those from the unlaundered towels the micro vacuuming technique was applied using the same sampling criteria (flow rate and area of towel sampled)

The results of micro vacuum sampling of laundered towels (and coveralls) are shown in table 3.

6.4.1. Micro Vacuum Sampling: HSL Contaminated Towel Laundered at Laundry A

This towel appeared to be still contaminated after laundering. The PCM discrimination counts gave a fibre density of 26 f mm^{-2} but a TEM PCME fibre count was almost four times this (100 f mm^{-2}). Although discrimination counts appear to under count compared to TEM counts (section 9.1) there is no full explanation for the discrepancy between these two values. Nevertheless they do clearly show that measurable levels of asbestos fibres remained after laundering.

A section (~ 2 cm^2) was cut from the towel and mechanically agitated in distilled water (3 minu in a ultra sonic bath). The fibres released were recovered by filtering the water through a 0.2 µ polycarbonate filter and examined using a scanning electronic microscope (SEM). The SEM image (figure 3) shows a typical range of fibres, many of which (the short, thin, straight fibres) were confirmed as being amosite asbesto by energy dispersive x-ray techniques.

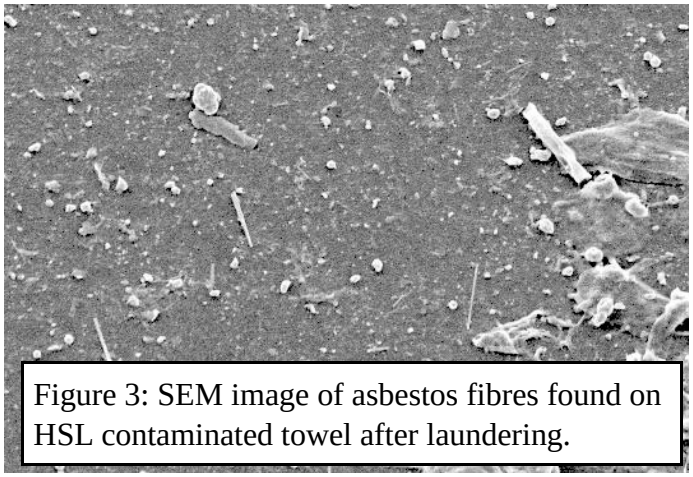

Figure 3: SEM image of asbestos fibres found on HSL contaminated towel after laundering.

6.4.2. Micro Vacuum sampling: Contaminated Towels Laundered at Laundry A

PCM discrimination counts gave asbestos fibre densities of between 11 f mm^{-2} and 19 f mm^{-2}. TEM (PCME) analyses produced similar results (15 f mm^{-2} to 37 f mm^{-2}) indicating that at these fibre densities the PCM discrimination method and TEM (PCME) method were comparable.

6.4.3. Micro Vacuum sampling: Contaminated Towels Laundered at Laundry B

The PCM discrimination count from a vacuum sample from a towel laundered at Laundry B was 38.3 f mm^{-2}. This was slightly greater than the values for similar samples from towels laundered at Laundry A; this difference was not significant as this value was within the 95% error range of the PCM discrimination counts.

Table 3: Micro Vacuum Sampling: Laundered Towels.

Sample No	Towel	Asbestos Fibre density (f mm^{-2}).		
		PCM #	PCM Discrimination	TEM PCME
HSL/07870/01	Towel A1: Laundry A.	584.53	19.1*	15.3 (7.4%)
HSL/07871/01		466.36	17.83*	37.1 (18.5%)
HSL/07875/01	HSL contaminated towel: Laundry A	292.01	26.1	99.8 (48.4 %)
HSL/07904/01	Towel A2 : Laundry A		16.8	20.4
HSL/07933/01	Towel A3 : Laundry A		11.9	
HSL/07934/01			19.4	
HSL/07941/01	Towel B1: Laundry B		38.3	43.4

* discrimination count (MDHS 87) using MDHS 59 counting rules instead of MDHS 39/4 counting rules. These samples included a large number asbestos fibres touching large non fibrous particle (>3 µm) Under MDHS 39/4 counting rules these 'touching' fibres would be uncountable but they are countable using MDHS 59 counting rules which allows these fibres to be counted.
# includes all fibres (asbestos and non asbestos).

6.5. Rotating Drum Sampling:

It was observed that many towels after laundering produced large amounts of 'fluff' when sampled in the rotating drum but apparently older (judged by appearance) towels produced much less. This was unexpected as 'fluff' was not found when sampling contaminated (used) towels. No asbestos fibres were found when samples of this fluff were examined using TEM analysis.

The results from rotating drum samples taken from laundered towels are shown in table 4.

6.5.1. Rotating Drum Sampling: New Towel Laundered at Laundry A

The PCM discrimination count from a new, unused towel laundered at Laundry A was 4.3 f mm^{-2}, (< 0.01 f ml^{-1}). No asbestos fibres were found using TEM analytical techniques.

6.5.2. Rotating Drum Sampling: Contaminated Towels: Laundry A

PCM discrimination counts gave fibre densities ranging from 4 f mm^{-2} to 19 f mm^{-2} and TEM PCME counts of 17 f mm^{-2} to 33 f mm^{-2}. One ten minute PCM fibre count gave an airborne fibre concentration of 0.06 f ml^{-1}, inside the rotating drum, but the others, and all the TEM PCME counts were at or below 0.01 f ml^{-1}.

6.5.3. Rotating Drum Sampling: Contaminated Towels: Laundry B

For two ten minute samples, PCM discrimination counts gave airborne fibre concentrations of 0.17 and 0.21 f ml^{-1} and fibre densities of 44.3 and 66.8 f mm^{2}. The TEM PCME value for a two hour sample was 0.03 f ml^{-1} (96.9 f mm^{2}).

Table 4: Rotating Drum Samples: Laundered Towels

Sample No	Towel	All fibres[$]		Asbestos fibre density			
		PCM		Discrimination[#]		TEM PCME	
		f mm^{-2}	f ml^{-1}	f mm^{-2}	f ml^{-1}	f mm^{-2}	f ml^{-1}
HSL/07868/01	Empty drum	2.53	<0.01				
HSL/07872/01	Laundry A: new HSL towel	209.76	0.09	4.3	<0.01	To sparse to analyse	
HSL/07874/01	Laundry A: Towel A4	482.95	0.31	15.52	<0.01	17.9	0.01
HSL/07902/01	Laundry A: Towel A5			18.46	<0.01	33.2	0.01
HSL/07906/01	Fluff from new HSL towel					No asbestos detected	
HSL/07928/01	New towel (not laundered)			0.64*	<0.01*		
HSL/07930/01	Laundry A: Towel A6			17*	0.06*		
HSL/07931/01				11.14	<0.01		
HSL/07862/01	Laundry A: towel A7			3.7*	0.01*		
HSL/07865/01				Filter overloaded by non asbestos particles			
HSL/07942/01	Laundry B: towel B1.			44.3*	0.17*		
HSL/07943/01				Filter overloaded by non asbestos particles			
HSL/07949/01	Laundry B: towel B2.			66.8*	0.21*		
HSL/07950/01				35.6	0.01	96.9	0.03

* 10 minute sample

[#] MDHS 87 techniques were used to differentiate between asbestos and non asbestos fibres: counting was then carried out on fibres (asbestos only) using the MDHS 39/4 counting rules.

$ includes both asbestos and non asbestos fibres

Note:- The fibre concentrations (f ml^{-1}) refer to airborne fibre levels inside the rotating drum and are not releases into the environment (e.g. a shower unit) where the greater air volume would result in a greatly reduced airborne fibre concentration.

7. COVERALLS:

Initially it was assumed, that as a result of work activity used coveralls would be contaminated with asbestos and sampling was not carried out on coveralls prior to laundering. Both sets of laundered coveralls (Laundry A and Laundry B) were selected at random from the laundry stores.

7.1. Micro Vacuum Sampling Laundered Coveralls:

Table 5: Micro Vacuum Sampling: Laundered Coveralls

Sample No	Coverall	Asbestos fibre density (f mm^{-2}).	
		Discrimination[#]	TEM PCME
HSL/07976/01	Laundry A: coverall A1	7.6	
HSL/07977/01		15.7	
HSL/07979/01	Laundry A: coverall A2	17.1	10.2
HSL/07980/01		13.8	
HSL/07944/01	Laundry B: coverall B1	1.91	
HSL/07951/01	Laundry B: coverall B2	2.4	No asbestos fibres found
HSL/07952/01		1.8	

MDHS 87 techniques were used to differentiate between asbestos and non asbestos fibres: counting was then carried out on fibres (asbestos only) using the MDHS 39/4 counting rules.

The results from micro sampling of laundered

coveralls are shown in Table 5. The PCM discrimination asbestos fibre densities of 8 f mm^{-2} to 17 f mm^{-2} for the laundered coveralls from Laundry A were similar to those for towels. Those from Laundry B, 1.8 - 2.4 f mm^{-2}, were significantly lower and fell within the error range of uncontaminated filters (i.e. below the lower limit of detection).

7.2. Rotating Drum Sampling: Laundered Coveralls

7.2.1. Rotating drum sampling: Laundered coveralls; Laundry A

The results of the rotating drum sampling of laundered coveralls from Laundries A and B are shown in Table 6. The PCM discrimination counts gave asbestos fibre densities of less than 4 f mm^{-2} (<0.01 f ml^{-1}) indicating that the asbestos fibre levels did not exceed background levels.

7.2.2. Rotating drum sampling: Laundered coveralls; Laundry B

One sample had a PCM discrimination count of 11 f mm^{-2} (<0.01 f ml^{-1}) but other comparable counts, including a duplicate, resulted in fibre densities of less than 4 f mm^{-2}.

Table 6: Rotating Drum Samples: Laundered Coveralls

Sample No	Towel	Asbestos Fibre density			
		Discrimination#		TEM PCME	
		f mm^{-2}	f ml^{-1}	f mm^{-2}	f ml^{-1}
	Empty drum	2.6	<0.01		
HSL/07946/01	Coverall B1: Laundry B.	3.5	0.01	2.6	0.01
HSL/07947/01		2.6	<0.01	No asbestos detected	
HSL/07963/01	Coverall B2: Laundry B.	1.5*	<0.01*		
HSL/07964/01		11.1	<0.01		
HSL/07972/01	Coverall A1: Laundry A	3.5	<0.01		
HSL/07981/01	Coverall A2: Laundry A	2.2	<0.01		
* 10 minute sample. # MDHS 87 techniques were used to differentiate between asbestos and non asbestos fibres: counting was then carried out on fibres (asbestos only) using the MDHS 39/4 counting rules.					

7.3. Coveralls Contaminated With Asbestos at HSL:

The initial work on laundered coveralls indicated that the laundering was efficient as very little evidence of asbestos remained after laundering. However, the histories of the coveralls were unknown and the absence of asbestos may have been the result of other factors, for example the coveralls may not have been exposed to asbestos prior to laundering. Therefore further work on coveralls that were artificially contaminated prior to laundering was carried out. The laundered coveralls previously tested were contaminated by agitating with a quantity of amosite asbestos (shaken for ¼ hour in a sealed plastic bag). Airborne samples of fibres released during further agitation in the rotating drum dustiness tester and micro vacuum samples from selected areas of the coveralls were collected. One of each pair of coveralls was moistened, prior to contamination, by spraying it with water from a handheld garden spray. This was to simulate the wet removal conditions

(asbestos liable to disturbance or removal must be 'wet' prior to it being disturbed). Each of these damp coveralls was agitated in the rotating drum dustiness tester (samples collected), dried and further agitated in the rotating drum dustiness tester (and samples collected).

The samples (filters) were examined using MDHS 87 asbestos discrimination counting techniques and the results from these analyses are shown in table 7. They clearly showed that all four coveralls were heavily contaminated with amosite asbestos, with fibre densities ranging from 357 f mm^{-2} to 5,125 f mm^{-2}. Airborne fibre densities of up to 7.8 f ml^{-1} were generated inside the rotating drum dustiness tester.

After sampling the coveralls were marked, packed in water soluble bags and returned to the laundries from which they were received. Each laundry was asked to launder the coveralls using their normal laundering techniques and return the coveralls to HSL.

Table 7: Fibre densities on coveralls contaminated with asbestos at HSL.

HSL No	Coverall	Weight amosite	Test Method	Asbestos fibre density+	
				F mm^{-2}	F ml^{-1}
HSL/12002/01	Coverall A 1	0.6 g	Rot. Drum: 121 min @ 10 L min^{-1}	603.3	0.19
HSL/12005/01	Coverall B 1	0.6 g	Rot. Drum: 120 min @ 10 L min^{-1}	2,228.2	0.71
HSL/12008/01	Coverall A 1 (leg)		Vac. After rot. drum	357.4	
HSL/12009/01	Coverall B 1 (arm)		Vac. After rot. drum	1,489.7	
HSL/12010/01	Coverall A 2	0.9 g*	Rot. Drum: 120 min @ 10 L min^{-1}	Over loaded	
HSL/07571/01	Coverall A 2 after drying		Rot. Drum: 120 min @ 10 L min^{-1}	5,124.8 #	7.8#
HSL/07572/01	Repeat of HSL/07571/01		Rot. Drum: 150 min @ 10 L min^{-1}	795.8	0.2
HSL/07574/01	Coverall A 2 (arm)		Vac. after R. drum	1,003.4	
HSL/07575/01	Coverall B 2	0.9 g*	Rot. Drum: 120 min @ 10 L min^{-1}	401.9	0.13
HSL/07576/01	Coverall B 2 after drying		Rot. Drum: 123 min @ 10 L min^{-1}	Over loaded	
HSL/07577/01	Repeat of HSL/0757601		Rot. Drum: 30 min @ 10 L min^{-1}	3,295.3	4.2
HSL/07578/01	Coverall B 2 (arm)		Vac. after R. drum	2,486	

* coverall dampened by spraying with 250 g of water. # re-suspension from overloaded filter
+ Fibre discrimination counts MDHS 87 techniques were used to differentiate between asbestos and non asbestos fibres: counting was then carried out on fibres (asbestos only) using the MDHS 39/4 counting rules.

7.4. Results From Coveralls Contaminated at HSL After Laundering:

After laundering the HSL contaminated coveralls were returned to HSL and tested for asbestos contamination using the same techniques employed previously. The asbestos fibre densities determined using MDHS 87 fibre discrimination techniques are shown in table 8.

None of the micro vacuum samples showed asbestos levels in excess of what would be accepted for a blank filter. This was also the case for rotating drum dustiness tester samples for three of the four coveralls. One sample from coverall A1 gave a result in excess of that expected from a blank filter but cross contamination was suspected, as blank samples from the rotating drum dustiness tester (run empty) also gave higher than expected results (6.4 and 13.1 f mm^{-2}). The asbestos fibre density for a repeat sample from the same coverall (A1) was similar to the low levels on the other three laundered coveralls. None of the tests, including the one where cross contamination was suspected, produced airborne fibre densities, inside the rotating drum dustiness tester, in excess of 0.01 f ml^{-1}.

Table 8: Fibre densities for HSL contaminated coveralls after laundering

HSL N°	Coverall	Test Method	Asbestos Fibre Density#		Comment
			F mm^{-2}	F ml^{-1}	
07017/02	MT Drum	Rot. Drum: 126 min @ 10 l min^{-1}.	6.4	<0.01	
07020/02	Laundry A: coverall A1	Rot. Drum: 130 min @ 11 l min^{-1}.	21.6*	<0.01*	* Suspected cross contamination: # repeat test
07034/02		Rot. Drum: 121 min @ 10 l min^{-1}.	1.8#	<0.01#	
07022/02	MT Drum	Rot. Drum: 134 min @ 10 l min^{-1}.	13.1	<0.01	
07023/02	Laundry A: coverall A2	Rot. Drum: 127 min @ 10 l min^{-1}.	4.5	<0.01	
07024/02	MT Drum	Rot. Drum: 131 min @ 10.5 l min^{-1}.	5	<0.01	
07026/02	Laundry B: coverall B1	Rot. Drum: 122 min @ 10 l min^{-1}.	4.2	<0.01	
07027/02	MT Drum	Rot. Drum: 121 min @ 10 l min^{-1}.	1.3	<0.01	
07028/02	Laundry B: coverall B2	Rot. Drum: 122 min @ 10 l min^{-1}.	4.5	<0.01	
07018/02	Laundry A: coverall A1 (arm)	Micro Vacuum samples	1.6		
07019/02	Laundry A: coverall A2 (leg)		4		
07021/02	Laundry B: coverall B1 (arm)		3.3		
07025/02	Laundry B: coverall B2 (leg)		6.3		
# MDHS 87 techniques were used to differentiate between asbestos and non asbestos fibres: counting was then carried out on fibres (asbestos only) using the MDHS 39/4 counting rules.					

8. HANDLING OF LAUNDERED TOWELS

Measurable levels of residual asbestos were found on towels after laundering and so a further test was carried out to examine the potential fibre releases when handling these towels in laundries. Large numbers of dry towels may be handled (shaken, folded and stacked) by the person carrying out this work, who then could be at greater potential risk than an asbestos removal worker using a

single towel when showering. To test this hypothesis forty laundered towels (20 from each of the two laundries used previously) were shaken, folded and stacked over an eighteen minute period. This was done in still air in a chamber ~2 m x ~2 m x ~2 m and the airborne fibre releases monitored. The person carrying out the work wore two sampling heads (operating at 10 L min^{-1} and 6.8 L min^{-1}) and two static pumps, one behind the worker (9 L min^{-1}) and one adjacent to the stacked towels (8.2 L min^{-1}) were also deployed. The airborne fibre concentrations were determined using the same fibre discrimination techniques as used previously and two samples were also analysed using TEM techniques.

The results (Table 9) show that up to 0.05 f ml^{-1} asbestos fibres were released from the towels. The presence of amosite asbestos fibres in two of the samples was confirmed using TEM techniques.

The laundered towels used in this test were selected at random with no prior knowledge of their use and the levels of asbestos contamination on these towels was unknown. To allow comparisons with the earlier tests four of the towels, selected at random, were subjected to similar rotating drum dustiness tests as those employed previously. The airborne asbestos fibre concentrations, inside the rotating drum are shown in table 10. They ranged from 0.01 to 0.12 f ml^{-1} (9 to 40 f mm^{-2}) and were similar to the results from the earlier test.

Table 9: Airborne fibre levels from shaking forty newly laundered towels over an eighteen minute period

Sample Nº.	MDHS 39/4 Discrimination counts#		TEM		Comments
	F mm^{-2}	F ml^{-1}	Nº. of fibres*	SF ml^{-1}	
07256/02	17.83	0.04	12	0.05	Personal
07257/02	10.5	0.03			Personal
07258/02	16.36	0.04	9	0.04	Static adjacent stack
07259/02	11.46	0.03			Static behind worker
* Number of amosite asbestos in 50 grid openings . MDHS 87 techniques were used to differentiate between asbestos and non asbestos fibres: counting was then carried out on fibres (asbestos only) using the MDHS 39/4 counting rules.					

Table 10: Rotating drum airborne fibre levels from towels used in shake test

Sample Nº.	MDHS 39/4 Discrimination counts#		TEM		Comments
	F mm^{-2}	F ml^{-1}	Nº. of fibres*	SF ml^{-1}	
07346/02	38.97	0.01			Laundry A
07349/02	40.21	0.12			Laundry A
07352/02	9.12	0.03			Laundry B

07355/02	18.56	0.05			Laundry B

Asbestos fibres identified using MDHS 87 techniques and counted using MDHS 39/4 count rules.

9. DISCUSSION

9.1. Fibre Counting Techniques:

All the samples contained large numbers of textile and other non-asbestos fibres. These other non asbestos fibres are likely to have included glass fibre. The non asbestos fibres are excluded from both PCM discrimination (MDHS 87) and TEM PCME counts. All the asbestos fibres identified using fibre discrimination techniques were counted using the MDHS 39/4 counting rules with the exception of a small number of samples where there were problems with high levels of non fibrous particles. This meant that many countable fibres were excluded using MDHS 39/4 rules and meaningful counts were not possible. These samples could however, be counted using MDHS 59 counting rules and although counts using these rules are generally slightly higher than those under MDHS 39/4 these difference were unlikely to be significant. Figure 4 shows a plot comparing the TEM PCME asbestos fibre densities and PCM discrimination fibre densities. The correlation coefficient R^2 (0.6) indicates that there is a reasonable agreement between the two methods (TEM PCME, PCM discrimination) of counting asbestos fibres. It is clear that at low fibre densities (below 25 f mm^{-2}) the agreement is good but at higher densities the PCM discrimination method appears to underestimate fibre densities. Although it produces an underestimate, the PCM discrimination counting is, for these samples containing mainly amosite asbestos, a quick and accurate method of assessing fibre densities on contaminated towels and coveralls. PCM discrimination fibre densities can be corrected using the best fit straight line equation $y = 0.268x + 8.764$.

9.2. What the values mean:

The levels of contamination found on the towels and coveralls were measured using fibre counting techniques on samples collected using two different sampling techniques, rotating drum dustiness testing and micro vacuuming.

The rotating drum dustiness tester mechanically agitates by tumbling the item under test in a uniform manner. It is a scientific test used to measure the potential for articles to release fibres under controlled and standardised conditions. Since the test is repeatable, it enables comparisons to be made between articles. However the test conditions do not reflect the nature, extent and duration of disturbance a towel or coverall would be subjected to during normal handling or use. In addition, the concentration values obtained from the tests while reported as airborne fibre units (f ml^{-1}) are derived from and are dependent on the selected test conditions particularly the drum volume and the sampling extraction rate. Consequently the results of the tests are not directly comparable with workplace situations or workplace exposure. However broad estimates of workplace levels can be made.

In general terms any workplace asbestos concentration will be significantly lower than the measured test result for the towels for the following reasons: much greater air volumes (the smallest modular shower unit is some 65 times more spacious than the rotating drum); much greater ventilation rates (the smallest shower unit operating at the minimum required extraction velocity of 0.1m s^{-1} has a ventilation rate of some 4 times higher than the sampling extraction rate); and much shorter handling times for users compared with the sampling periods (up to 2 hours). Therefore the highest measured test result of 0.21 f ml^{-1} (10 minute sample) for a laundered towel would produce an airborne fibre concentration of < 0.001 f ml^{-1} in the smallest modular shower unit operating with the minimum ventilation rate.

Micro vacuuming results in a fibre density on the filter on which the sample is collected. This is dependent on a wide range of variables, many of which were uncontrollable. Consequently assessing what these values mean is difficult. However, as an attempt to quantify these values in real terms, a number of observations can be made:

- 10 f mm^{-2} is the lower limit of detection of the fibre counting techniques, any fibre densities of less than 10 f mm^{-2} can be regarded as being asbestos free.

- Therefore although dependent on a range of factors (uniformity of deposit, percentage of towel surface sampled) it can, for the samples measured here, be assumed that if the fibre density is in the range 10 to 20 f mm^{-2} then the level of contamination is probably very low.
- Fibre counting under MDHS 39/4 counting rules has errors that approximate to, half to double the counted value (95% confidence limits). Consequently although some results may appear very different, statistically they are not. For example the laundered fibre density for towel A3 (13 f mm^{-2}) prior to laundering is not significantly different to the value (19.4 f mm^{-2}) measured after laundering.

For each sample collected using the rotating drum dustiness tester there is a relationship between fibre density (f mm^{-2}) and airborne concentration (f ml^{-1}). However, this relationship is unique to each sample and does not extend to other samples collected using the rotating drum or by other sampling techniques (micro vacuuming).

9.3. Fibre Releases with Time:

A comparison of the airborne asbestos fibre concentrations within the rotating drum collected over ten minute test periods compared to those collected over two hours suggests that most asbestos fibres were released during the first ten minutes of the test. Table 11 shows the results for the two hour samples recalculated assuming that 83% of the fibres were released in the first ten minutes of the disturbance inside the rotating drum. [83 % is an arbitrary factor included because, although most of the fibres are released during the first ten minutes a small unknown proportion will have been released in the remaining one hundred and ten minutes of the test].

For two towels for which two hour and ten minute airborne asbestos fibre concentrations were available the recalculated values (assuming 83 % of fibres are released in the first ten minutes of the two hour test) and the ten minute test values, were not significantly different. The recalculated values fall with in the 95% confidence envelope (½ - 2X the value) of the ten minute test values.

The recalculated values (10 minutes; 83 % of fibre release) were similar to the values produced in the shake test (0.02 - 0.11 f/ml cf. 0.03 - 0.05[+]) and are also very similar to the rotating drum tests carried out on four of these 'shake test' towels (0.03 - 0.12 f/ml).

Table 11: Comparison of rotating drum airborne asbestos concentrations recalculated assumi 83% of the fibres were released in the initial ten minutes with the original two hour; actual te minute samples and laundry shake test values

Sample No	Discrimination 2 hour sample	Discrimination 10 min : 83%	Discrimination ~ 10 min. samples	Towel
Hsl07851/01	<0.01 (0.007)[+]	0.04		'dirty' Ex hygiene unit towel
Hsl07860/01	<0.01 (0.003)[+]	0.02		
Hsl07862/01	<0.01	0.02		
Hsl07874/01	<0.01 (0.01)[+]	0.1		Laundered towel (laundry A)
Hsl07931/01*	<0.01	0.04	0.06	
Hsl07902/01	<0.01	0.06		
Hsl07862/01*	overloaded		0.01	laundered towel (laundry B)
Hsl07942/01*	overloaded		0.17	
Hsl07949/01*	0.01 (0.03)[+]	0.11	0.21	
07256/02			0.04 (0.05)[+]	Laundry shake etc. Tests (40 towels ~ 18 min)
07257/02			0.03	
07258/02			0.04 (0.04)[+]	
07259/02			0.03	
07346/02			0.01	Rotating drum: selected towels from shake test
07349/02			0.12	
07352/02			0.03	
07355/02			0.05	

* duplicate 2 hours and 10 minute samples.
+ = TEM value

9.4. Towels:

The results showed that whilst laundering removes much of the asbestos contamination, especially from heavily contaminated towels, it is not one hundred percent efficient . Although towels appeared clean (visual examination) trace amounts of asbestos remained on towels after laundering, using current laundering best practice.

Table 12 summarises the asbestos fibre levels on towels examined before and after laundering.

The degree of initial contamination was variable (5 f mm^{-2} to 154 f mm^{-2}) and whilst laundering clearly reduced high levels of contamination for the HSL contaminated towel (to < 30 f mm^{-2}) very little (if any) improvement was observed for the towels which were lightly contaminated (still 11.4 - 18.5 f mm^{-2}). This suggests that although some fibres maybe easily removed by washing others are much more strongly bonded and are not easily removed, and remain after being laundered.

One intercepted towel appeared to be heavily contaminated before laundering (154 f mm^{-2}) and to have greatly reduced contamination after laundering (~18 f mm^{-2}) but a degree of caution is required as these values were the result of micro vacuum sampling and could be explained by sampling variability.

Although some towels will either pick up little or possibly no contamination in use, others may, especially if misused, become very heavily contaminated. Contamination will not necessarily be visible, therefore all towels taken into the shower unit must be treated as contaminated and either disposed of as contaminated waste or bagged and sent to an appropriate laundry.

Table 12: Comparison of fibre densities from contaminated towels before and after laundering

Towel	Sampling method	Pre laundering		After laundering	
		PCM discrimination counts#: f mm^{-2} (f ml^{-1})	TEM PCME	PCM discrimination counts# f mm^{-2} (f ml^{-1})	TEM PCME
New unused HSL	Vacuum Rot. drum	7.6[A] 0.64 (<0.01)*		4.3 (<0.01)	No asbestos found
Contaminated HSL	Vacuum	436.3		26.1	99.8
A1	Vacuum	154.2		19.1 17.8	15.3, 37.1
A2	Vacuum	27.6		16.8	20.4
A3	Vacuum	13.1	19.3	11.9 19.4	
A4	Rot. drum&	13.4 (<0.01)	22.4 (<0.01)	15.5 (<0.01)	17.9 (0.01)
A5	Rot. drum&	21.3 (<0.01)		18.5 (<0.01)	33.2 (<0.01)
A6	Rot. drum&	8.1 (<0.01)	10.0 (<0.01)	17 (<0.06)* 11.14 (<0.01)	
A7	Rot. drum&	5.4 (<0.01)		3.7 (0.01)*	

* ten minute sample.
PCM count undiscriminated.
MDHS 87 techniques were used to differentiate between asbestos and non asbestos fibres: counting was then carried out on fibres (asbestos only) using the MDHS 39/4 counting rules.

9.5. Handling of Towels in Laundries

A test on the handling of freshly laundered towels (in the laundry) showed that measurable levels of airborne asbestos fibres can be released during such procedures. The vigorous shaking used to simulate handling in this test was probably more violent than the disturbance that towels are likely to be subject to in practice. Also it is likely, even in poorly ventilated laundries, that air extraction will be greater than in the still air situation employed here. Although rotating drum dustiness tests carried out on representative towels from this test (shake, fold, stack) indicated that the laundering efficiency was similar to that observed previously, it is possible that laundering at other laundries could be less efficient. In principle it is possible that an operative could carry out similar handling activities for extended periods (four hour) but the work patterns, work load and the laundering facilities (washing machines) at the two laundries visited suggested that this would be unlikely. Nevertheless, as measurable levels of airborne asbestos fibres can be released when handling freshly laundered towels, under CAWR, precautions should be taken to prevent or minimise exposure. These precautions should include:

1. Good mechanical air extraction (negative pressure).
2. Limited access: a clearly defined, lockable room(s) to which only designated staff are allowed access.
3. Regular air monitoring.
4. High hygiene standards.

9.6. Coveralls:

The size of the coveralls was such that the degree of disturbance in the rotating drum dustiness tester was less than that experienced by the towels. Therefore direct comparisons between fibre densities for towels and coveralls may not be valid.

Both the initial tests, on laundered coveralls of unknown provenance, and the later tests on laundered coveralls which had been artificially contaminated, indicated that very little or no asbestos remained after laundering. The one rotating drum dustiness result that was above the level for blank filters was only marginally so and was probably the result of cross contamination from previous tests. When the air volume of the rotating drum dustiness tester is taken into consideration then airborne asbestos fibre releases will be unlikely to exceed 0.001 f ml^{-1}. Coveralls are made from different fabrics (textiles) to towels and the laundering process appears to be much more efficient at removing asbestos fibres from these fabrics. The laundering of asbestos contaminated coveralls which have been used when working on asbestos removal or renovation situations appears to effective. The laundered coveralls appear to be free of asbestos contamination.

10. CONCLUSIONS AND RECOMMENDATIONS:

Work undertaken in this study has shown that clean towels can become contaminated by asbestos. Contamination could arise from improper use or ineffective decontamination, which suggests that decontamination procedures are not being followed properly for sufficient time. As such, employers need to ensure asbestos removal operatives decontaminate themselves thoroughly for sufficient time and follow the correct procedures.

Misuse, including inadequate showering, may lead to asbestos fibres being transferred to towels. As such, individuals should begin the drying process in the shower cubicle, where they should dry themselves as thoroughly as possible. The used towel should them be treated as contaminated and dealt with appropriately. The drying process can be completed, if necessary, in the clean end of the hygiene facility using a fresh towel, which if it remains there can be deemed to be uncontaminated. Towels used beyond the clean end of the hygiene facility should never be taken home for laundering.

Although current laundering best practice removes much of the asbestos contamination, especially from heavily contaminated towels, it is not one hundred percent efficient. Low levels of residual asbestos were found on towels after laundering and the removal of all traces of asbestos from towels appears to be very difficult. Whilst this is unlikely to present a risk to an asbestos worker using a single towel when showering, given the minimal time spent shaking it and the well ventilated and

damp conditions, it could present a risk to laundry workers, who may handle large numbers of dry towels, depending on the circumstances, conditions and procedures in operation.

The position regarding coveralls is more clear cut, as laundered coveralls appear to be free of asbestos contamination.

The standards of cleanliness and asbestos related precautions taken at the two laundries visited were very high. However, the telephone survey showed that conditions elsewhere were variable. All laundry operators, whether they be independent specialist commercial laundries or in house laundries operated by asbestos removal companies need to assess the potential risks arising from this work and ensure the necessary precautions are in place. As a minimum, the precautions included in paragraph 9.5 should be in place.

10.1. Recommendations:-

1. Employers should ensure that asbestos workers decontaminate themselves thoroughly and properly, by taking sufficient time, care and attention, so that the decontamination process is effective.

2. Each worker should leave a clean towel in the shower section when transiting from the clean to the dirty end of the hygiene unit on his way into the removal enclosure.

3. On returning via the dirty end of the hygiene unit all workers should shower thoroughly and start the drying process in the shower section before returning to the clean end of the hygiene unit.

4. Any towel taken into the shower section should be treated as contaminated and be either disposed of as asbestos waste or bagged up for washing at a laundry which has the facilities and expertise to launder asbestos contaminated items.

5. Having dried themselves thoroughly in the shower unit the workers can finish drying in the clean end using a fresh towel, which never having progressed beyond the clean end is deemed uncontaminated and requires no special laundering.

6. Coveralls used during asbestos removal or renovation work should be treated as contaminated with asbestos and removed in the dirty end of the hygiene unit. These contaminated coveralls must either be disposed of as asbestos waste or bagged up for washing at a laundry which has the facilities and expertise to launder asbestos contaminated items.

7. Contaminated towels should be bagged and laundered separately to contaminated coveralls.

8. Laundries dealing with asbestos contaminated items should assess the potential risks arising from this work (both pre and post laundering) and take precautions to prevent or minimise their employees' exposure to asbestos (These precautions should include good mechanical air extraction (negative pressure); limited access: a clearly defined lockable room(s) to which only designated staff are allowed access); regular air monitoring; and high hygiene standards).

11. FURTHER WORK

This work has shown that laundries that specialise in handling asbestos contaminated laundry can be operated safely and are effective in removing asbestos from coveralls. The areas that may require further work are:

1. To investigate whether it is possible to launder towels in such a way that they become asbestos free.
2. To investigate risks at less efficient laundries and determine how effective are non specialised laundries at handling hazardous materials such as asbestos.
3. To investigate the need to filter discharged air from tumble dryers.

12. REFERENCES

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13. FIGURES:

Figure 4: Graph showing comparison between PCM discrimination and TEM PCME fibre densities.