Airborne Fibre and Asbestos Concentrations in System Built Schools

Garry Burdett*, Steve Cottrell and Catherine Taylor
Health and Safety Laboratory, Harpur Hill, Buxton, Derbyshire, UK, SK17 9JN

e-mail Garry.Burdett@hsl.gov.uk

Abstract: This paper summarises the airborne fibre concentration data measured in system built schools that contained asbestos insulation board (AIB) enclosed in the support columns by a protective steel casing. The particular focus of this work was the CLASP (Consortium of Local Authorities Special Programme) system buildings. A variety of air monitoring tests were carried out to assess the potential for fibres to be released into the classroom. A peak release testing protocol was adopted that involved static sampling, while simulating direct impact disturbances to selected columns. This was carried out before remediation, after sealing gaps and holes in and around the casing visible in the room (i.e. below ceiling level) and additionally round the tops of the columns, which extended into the suspended ceiling void. Simulated and actual measurements of worker exposures were also undertaken, while sealing columns, carrying out cleaning and maintenance work in the ceiling voids. Routine analysis of these air samples was carried out by phase contrast microscopy (PCM) with a limited amount of analytical transmission electron microscopy (TEM) analysis to confirm whether the fibres visible by PCM were asbestos or non-asbestos. The PCM fibre concentrations data from the peak release tests showed that while direct releases of fibres to the room air can occur from gaps and holes in and around the column casings, sealing is an effective way of minimising releases to below the limit of quantification (0.01 f/ml) of the PCM method for some 95% of the tests carried out. Sealing with silicone filler and taping any gaps and seams visible on the column casing in the room, also gave concentrations below the limit of quantification (LOQ) of the PCM method for 95% of the tests carried out. The data available did not show any significant difference between the PCM fibre concentrations in the room air for columns that had or had not been sealed in the ceiling void, as well as in the room. Occupant exposures during normal classroom teaching activities in areas that had undergone remediation were also monitored with much greater use of TEM analysis to determine the asbestos fibre concentration. No asbestos fibres were found in the TEM analysis of samples of classroom air from seven schools, after remediation had taken place. Occupant exposures in one school and one office building have been monitored before remediation and only one asbestos fibre was found in each set of samples analysed. The average monitored occupant exposures to asbestos in CLASP buildings was <0.00005 f/ml, an order of magnitude lower than previous measurements in UK buildings.

Key Words: asbestos, buildings, schools, airborne, concentrations, PCM, TEM, CLASP, sampling.
1. Introduction
In the summer of 2006, after asbestos removal contractors had carried out asbestos removal work at a system built (CLASP) school building, the laboratory carrying out clearance monitoring obtained concentrations of airborne fibres above the ‘clearance level’, when, as part of deliberate disturbance they struck the support columns in the rooms. This finding was reported to the Health and Safety Executive (HSE) in September and prompted a rapid assessment of the causes of the fibre release by HSE inspectors, with support from the Health and Safety Laboratory (HSL).

The initial HSE/HSL investigation confirmed the clearance laboratories own findings that the airborne fibre release came from the columns and consisted mainly of amosite fibres generated from the asbestos insulating board (AIB) that had been installed to provide fire protection to the structural steel columns supporting the building structure. The AIB was enclosed by a metal casing around the column but leaked fibres into the room when the column was struck. The main source of fibres appeared to come from gaps where the two halves of the steel casing joined together. Also some of the casings had been damaged due to drilling through them to attach various items or from improper window replacement. Some debris from the original installation also appeared to have been swept into and around the base of the column in the gap behind the skirting board. The failure of the enclosure to prevent airborne fibre release into the classroom when the column casings were subjected to impacts was a source of concern, as it would increase the asbestos exposure and risk to the occupants and maintenance personnel. Also as enclosing asbestos is one of the remediation methods recommended in HSE guidance, an evaluation of the causes of the airborne release and assessing ways to improve the effectiveness of the enclosures was seen as a high priority.

After further field sampling work and data gathering had confirmed the primary cause for the release of fibres into the room (damaged and /or poor sealing column casing) and that sealing of gaps in the casing was an effective ways to minimise the release into the room, an initial advisory note was prepared and circulated by HSE in mid-October, before the half-term holiday. The note was sent to the Directors of Education/Children’s Services in England, Scotland and Wales and Governing Bodies of Foundation, Voluntary Aided and Independent schools, informing them of the potential for fibre release and requiring them to identify Mark 4 and 4B CLASP buildings; and to take action to seal any visible gaps in and around the column casings through which asbestos could escape directly into the room. Following this initial advice further work was carried out to assess airborne fibre levels using both routine phase contrast microscopy (PCM) with the use on selected samples of analytical transmission electron microscopy (TEM) to confirm the actual concentration of asbestos fibres present. This information was fed back to a CLASP advisory group [1, 2] (Burdett, 2007 & Burdett, 2008), which included representatives from HSE policy, sector and operational groups, HSL, Department for children, schools and families (DCFS), local government employers, unions and the building manufacturer. Its terms of reference were to ensure duty holder awareness of the issues, providing guidance, evaluating compliance and effectiveness of remedial action and agreeing a communication strategy for the education sector.

This paper summarises the airborne fibre concentration data collected in CLASP system built schools that had asbestos insulating board (AIB) in the support columns.

1.1. Description of the CLASP construction and occurrence of asbestos
The school where the escape was first noticed was a particular type of system built construction known as CLASP (Consortium of Local Authorities Special Programme). The CLASP concept was started in 1957 for the purposes of improving the construction and delivery of schools and used a systematic form of construction based largely on pre-fabricated elements. The system has a wide usage with some 3500 buildings in the UK including: primary and secondary schools, hospitals, universities, offices fire and ambulance stations. Several marks / redesigns of the building took place from 1957 –1980 when asbestos containing products were specified for use in the buildings. These were the mark 2, 3, 4 and some mark 5 structures. It should be noted while some asbestos products may always have been included, the majority of buildings were locally adapted by private and public
architects, who may have added additional asbestos products, or even have substituted some of the commonly specified asbestos products. The wide involvement of local architects means that there is considerable variety in the design between different buildings and where the asbestos may or may not be present. Details on where and which types of asbestos would normally be present were first circulated by CLASP to all Local Authorities in 1974 and this information has since been updated.

The use of AIB insulation in the columns was a common design feature and must be assumed to be present, in CLASP schools built before 1980, unless the building survey shows otherwise. It should be noted that in some mark 4 buildings the column casings were moulded from asbestos wood containing about 25% chrysotile, however no examples of these were found in the buildings examined in this survey. Figure 1 shows the external appearance of the column with a gap in the columns casing. Figures 2 - 4 shows examples of the use and appearance of AIB in the columns. A variety of configurations were found with AIB attached to the column rather than the casing and residual layers of material where the AIB had been removed. Off-cuts and debris could sometimes be present at the top and bottom of the columns and was probably placed there during the installation.

![Figure 1](image-url)

**Figure 1:** External appearance of the column showing an example of a gap in the casing.
Figure 2: Schematic diagram of use of AIB in the CLASP columns
Figure 3: Example of a column casing with AIB attached to one side of the casing. The torch beam shows where the AIB has fractured due to a screw being placed into the casing. A hole is visible in the side of the casing and visible debris shows that friable material was present.

Figure 4: View of base of column from which the casing was removed.
AIB was also commonly used in fire critical evacuation routes, fire risk areas or areas where there may be damp e.g. in suspended ceilings in entrances, in porches or over recessed areas and kitchens or in stud walls in stairwells, at high levels in halls and kitchens. Most AIB contained about 20% asbestos with Amosite being the predominant asbestos type present. Other forms of asbestos products are also commonly found in pre-1980 CLASP buildings, the most common being vinyl floor tile, asbestos cement sheet and moulded fittings, stair fittings, cloth fire breaks in ceilings voids. The vast majority of these would contain chrysotile asbestos. Some of the pre-cast concrete panels on the outside of the buildings also contained actinolite asbestos.

2. Method

2.1. Sampling strategy

As peak releases of airborne asbestos fibres will occur only infrequently it is much more convenient to simulate a peak release episode, using a standardised protocol. Simulation also allows pre-planning and the use of appropriate controls to prevent the spread of asbestos and the exclusion of other building occupants. The extent of force applied and the amount of damage inflicted on the ACM during the simulation will have a direct influence on the amount of airborne fibres released. The monitored fibre concentration is also influenced by a number of other sampling and environmental factors, e.g. the period of sampling and of disturbance, the closeness to the source of the fibre emissions, the use of personal sampling, the use of containment, the amount of ventilation / mixing of air.

Personal sampling using small lower flow rate battery pumps to sample air through a filter placed close to the breathing zone is the preferred method of collecting workplace occupational samples. While this is appropriate for maintenance workers who may carry out work in less accessible areas (e.g. ceiling voids) and directly disturb the asbestos, its applicability for monitoring pupils and teachers for background levels is less clear cut, besides the practical difficulties involved. Even for simulated short-term peak releases from impacts, the sampling rates achievable from personal sampling pumps will allow only concentrations above the control limit to be measured (e.g. a 10 minute personal sample has a limit of quantification (LOQ) of 0.24 f/ml ; see HSG 248 [3]). Therefore higher flow rate static sampling was used for occupancy sampling and most of the peak release simulation sampling to allow an improved LOQ.

Longer-term sampling to measure the average exposure during normal occupation is more demanding particularly in schools where there is a greater need to supervise the sampling and where pump noise will be more of an issue. In general, the shorter school day and the need for increased supervision, favours the use of higher flow rate (e.g. 8 –16 l/minute), heavier and more noisy sampling pumps, to take static samples over one school day. The analytical sensitivity of a clearance / background sample (based on 480 litres sampled onto a 22 mm diameter exposed filter area with 1.5 mm² examined by PCM) is 0.0003 f/ml based on a half fibre counted. However, in practice as blank filters have background fibre counts, the limit of detection is some ten times higher 0.003 f/ml. For the purpose of clearance indicator sampling, when it is important to determine whether the measured fibre concentrations can be considered to have a high probability to be above background, the acceptable concentration is set at <0.010 f/ml.

Fibre counting has poor statistical precision. This means that individual results must be compared carefully to assess whether any differences are actually present. Particles sampled onto a filter at best have a random distribution. This means that the precision of the count is limited by the underlying ‘Poisson’ statistics. The precision is usually expressed in terms of the confidence interval, which defines the upper and lower limits expected for a defined percentage of repeat counts. For example 95% confidence limits mean that on average 19 of the 20 values from repeat counts would be within the upper and lower limits. For low counts the lower confidence limit is 0, so a one-sided upper 95% confidence interval is used. For a count of 0 it is 95% probable that the count is < 3 fibres. This is used
as the limit of quantification for TEM analysis where there is normally no background of asbestos fibres on the blank membrane filter.

For any sampling in schools extensive communications with the local authorities, head teachers, governors, teachers, teaching unions and parents is necessary particularly if occupant sampling is to be carried out. Gaining access and sampling is therefore very time consuming and it was realised early on that working with local authorities and a number of local United Kingdom Accreditation Service (UKAS) accredited local sampling and PCM analysis laboratories was the only possible way to gather significant amounts of data in the short time period available. Due to several laboratories being involved, it was important that familiar routine sampling protocols were used and that the results of the PCM analysis was fed back to the interested parties and passed on to HSL.

The difficulties of access and communications, the use of local resources and the short time available to collect the data meant that it was not possible to implement a statistical sampling design to randomise the schools, classrooms and columns tested. The concern was to focus on whether we could detect columns that were likely to release airborne fibres and effectively remediate the release. This inevitably biased the sampling to the schools, which were thought to have the greatest amount of potential damage and the testing of columns that had physical damage or visible gaps. HSL in a later sampling exercise did set out to test columns that were judged to be in a reasonable to good condition.

### 2.2. Sampling and analysis methods

To assess peak releases from simulated disturbance of the columns a disturbance protocol was adopted, which was closely based on what is routinely used by PCM laboratories for the clearance air testing, in stage three of the four-stage clearance procedure detailed in HSG 248. At the school where the problem was first found the sampling laboratories had already developed a protocol which involved hitting of the column casing, slamming doors and sitting/jumping on the window shelf a number of times. The exact disturbance activity depended on the columns under test with the disturbances being repeated between 3-5 times at the start of the sampling period. This procedure along with the requirements for static air sampling as described in HSG 248, was adopted for the peak release testing of columns for both before and after remediation.

Static air samples were collected by sampling air through a 0.8 or 1.2 µm pore size mixed cellulose ester membrane filter at calibrated sampling rates of 8 l/minute or greater. This was used to collect a minimum sampling volume of 480 l over a period of around 60 minutes (or less at higher flow rates). The standard PCM fibre counting method was used (see HSG 248 annex 1) at X500 magnification to assess the concentration of visible >5 µm long fibres with aspect ratios > 3:1 and widths <3 µm. It should be noted for the purposes of this report that all data collected were recalculated based on the number of fibres and fields of view counted and the air volume sampled, assuming a 380 mm² exposed filter area and a graticule area of 0.0075 mm².

For sampling occupant exposure to asbestos during normal occupation, higher volumes of air need to be collected, preferably by extending the sampling period to get a more representative sample of the average exposure. A target sample volume of 3000 l over a minimum period of one school day was set with the filter being monitored for signs of overloading of particulates (colour changes from white to light-mid grey). After sampling was completed a half filter was cut using a scalpel blade and prepared and counted at x 500 by PCM analysis in the normal way (see HSG 248). A portion of the remaining filter was prepared and analysed by analytical electron microscopy. The gold standard for this type of analysis is the International Standard Organisation ISO 10312:95 [4] method based on transmission electron microscopy (TEM) which uses a combination of both energy dispersive x–ray analysis (EDXA) and electron diffraction (ED) to identify the asbestos fibres and magnifications of 10,000 to 20,000 to count and measure the asbestos fibres. The results can be expressed in terms of PCM equivalent asbestos fibres (approximately the same size of fibres counted by PCM) for the purposes of assessing exposure and risk.

One day of sampling represents only a snapshot of the occupant’s average exposure and several days of sampling were preferred. In practise, it was found that a sequence of daily samples spread over
several weeks was the more acceptable method for the occupants for collecting samples. This gave several individual results that can be averaged or “pooled” to give a better estimate of the cumulative average exposure to the occupants, as well as the range of individual daily exposures.

Personal sampling for fibre concentrations with PCM analysis of the fibre concentrations, as described in HSG 248 was used to monitor actual and simulated maintenance and cleaning activities. The PCM and TEM results represent data collected from a number of laboratories, all of which were UKAS accredited and hence meet the requirements of ISO 17025[5].

3. Results
Table 1 summarises the PCM data from schools for various activities, some later PCM data from specific maintenance activities are given separately.

3.1. PCM results from disturbance of unsealed columns.
After HSE’s initial investigation of the reported findings and it had been confirmed that amosite asbestos fibres were being released to air, the emphasis of the monitoring was on the effectiveness of the remedial action. The PCM data available from peak disturbance testing from some 31 air samples are summarised in figure 5. Some 60% of the samples exceeded 0.01 f/ml with the highest value in a school building being 0.44 f/ml.

The columns selected for peak release testing were generally chosen to represent a worst-case situation where there was visible damage to the casing (e.g. from installation of fire alarms) and / or obvious gaps were present. Columns adjacent to improperly or poorly replaced windows and with attached doors were also preferentially chosen to test, as the AIB would have been subject to greater damage. Some columns have been tested more than once or had more than one air sample collected. Generally, it was reported that in the same building, the more damage to the column casing and the greater area of visible gaps, the higher the fibre concentration measured.

Figure 5: Distribution of PCM fibre concentrations from disturbing hitting the columns.
3.2. PCM results from samples taken after sealing columns and cleaning the area.

The key issue for HSE and the duty holders was to determine whether the recommended advice to inspect the column casings for obvious holes and gaps and to seal them to increase the integrity of the enclosure was successful in minimising peak releases. Figure 6 summarises the results from 95 samples collected during the peak release testing of columns after fully sealing all gaps visible in the room as well as the top of the column in the ceiling void and cleaning the area. The distribution of the fibre counts is grouped around the limit of detection with a slightly elongated tail, suggesting that a few columns were still giving peak fibre release above the LOQ, even after complete sealing has taken place (including above ceiling). The overall level of the peak release was relatively low with a mean of 0.004 f/ml with about 5% of the samples exceeding the LOQ (0.01 f/ml), the highest result being 0.058 f/ml.

The results from peak release testing of 14 columns where all the gaps visible in the room has been sealed and taped but the top of the column left unsealed and the area not cleaned, gave mean and median concentrations of 0.006 and 0.002 f/ml respectively, with the highest single result of 0.032 f/ml.

![Figure 6: PCM results from disturbance testing of fully sealed columns after cleaning the room (the different coloured column at 0.003 f/ml represents the limit of detection).](image)

3.3. PCM results measured during normal use after remediation.

Figure 7 summarises 96 measurements after the classrooms were reoccupied and in normal use. This has a similar distribution to that found in the peak release testing in figure 6. However in an occupied room there are several sources of non-asbestos fibres (e.g. paper fibres and fine synthetic fibres) from the presence and activities of the occupants and is likely to substantially overestimate the asbestos fibre concentration. A number of samples (44) were taken after the remediation but before reoccupation and are also summarised in figure 7. Although some limited activity may have been present, this represents the best assessment estimate of the background level of fibre counts without any known disturbance.
3.4. Further PCM results from investigations of the effectiveness of remediation. 

The effectiveness of sealing to the ceiling height was studied in the original school with columns that gave high releases. Table 2 gives an example of the PCM results found when testing a column where several of the ceiling tiles around the column were damaged / displaced and shows that there were a significant reduction in PCM fibre concentrations even when the ceiling void was poorly isolated from the room. The TEM analysis of samples after sealing gaps below the ceiling detected 1 PCME amosite fibre, equivalent to an analytical sensitivity of 0.0016 f/ml.

At other columns in the same school releases from columns during peak disturbance testing were monitored adjacent to the columns at both ground level and inside the ceiling void (with ceiling tiles replaced). The results prior to remediation in table 3, showed that peak fibre emissions were relatively low at room level but increased significantly at one position after remediation. A similar low value followed by an increase was seen in all three ceiling void samples. The most likely explanation for these increases was that the maintenance personnel working in the ceiling void released fibres into the air so that when sampling after remediation commenced (<1 hour later) increased airborne fibre concentrations were still present. However as the ceiling voids were interconnected it is not impossible that some brush testing in the ceiling void elsewhere may have also contributed to the levels. Either way this data showed that disturbing and working in the ceiling void (in this case using experienced asbestos removal contractors who had sealed many tens of such columns) there is a greater possibility for exposures to occur.

3.5. PCM results while carrying out remedial work on columns.

Only a limited amount of data (12 samples) was available during the sealing of the column casings and the tops of the columns in the ceiling void, which gave a mean and median of 0.004 f/ml with >95% of the results being below the LOQ. However, as these were static samples at room level they may have underestimated the exposure from work in the ceiling voids. A larger number of static samples were collected when filling gaps and taping of the seams of the column casings in the room areas. As the

**Figure 7:** Comparison of PCM fibre concentrations measured in unoccupied and normally occupied classrooms after remediation.
tape was being firmly pressed against column casing up to the ceiling, this flexing of the casing would cause a more vigorous disturbance than someone leaning or pushing against the column. The distribution of the individual results are given in figure 8, based on 188 individual PCM samples.

![Figure 8: PCM air monitoring results from 188 samples taken during the taping of the vertical seams of the columns and surrounding joints.](image)

3.6. Cleaning and maintenance worker exposures

Twenty PCM analyses of samples collected by persons inspecting columns and ceiling areas gave mean and median concentrations of 0.004 and 0.002 f/ml respectively. The majority of samples were static samples by the inspection areas and may underestimate personal exposures when looking into the ceiling voids.

Three school cleaners who wore personal samplers during normal cleaning activities in a school that was considered to have a potential problem had measured PCM concentrations of 0.003, 0.011 and 0.014 f/ml giving an average of <0.01 f/ml.

Some simulated maintenance work was carried out at the most contaminated school and one other. The PCM results are summarised in table 4. The highest results came from a ceiling area where AIB ceiling tiles were present, so the settled dust on joists etc. was brushed rather than the surface of the AIB tile.

3.7. TEM results for asbestos fibre concentrations in schools before remediation

Since advice was issued so rapidly it was not possible to carry out a programme of monitoring asbestos fibre concentrations in schools by analytical TEM before remediation had taken place. The one school where data was obtained was reported to have a chrysotile asbestos board in the column and cannot be seen as representative of the amosite containing AIB. The calculated pooled result from two samples taken in different areas gave an analytical sensitivity (based on 1 asbestos fibre seen) of 0.00005 f/ml with a limit of detection of <0.0003 f/ml. Only one PCME asbestos fibre (chrysotile) was detected showing that the airborne exposures were low.

It was however possible to carry out prolonged sampling in an ex-school CLASP 4 building used as offices. No remediation of the columns had been carried out, which contained amosite AIB attached to the columns casings. The sampling strategy was to collect week long samples during the day (8 am
to 6 pm) to capture normal occupation and cleaning activity. Two samplers were set up one at a flow rate of 3.2 l/minute and one at 1.6 l/minute in two office rooms. Both sampling heads were positioned above radiators where there would be a good convective mixing of room air and close to sets of double doors. One sampler was particularly close to a set of doors, which vibrated the column when opened and closed and visible gaps were present in the columns around the windows. Even though extended counting was carried out on the samples, only 1 asbestos fibre (amosite) was found in the TEM analyses of the 10 samples collected over 5 weeks. As ~100 grid openings were counted in each sample, the average values for the building can be calculated from the pooled individual samples (see Table 1). This gave a calculated concentration for PCME asbestos fibres equal to the analytical sensitivity of 0.000005 f/ml and an upper 95% confidence value of <0.000024 f/ml for continuous daytime monitoring over the five-week period. TEM airborne asbestos concentrations in occupied schools after remediation

In total, 31 individual samples taken in eight occupied schools were analysed by TEM. Seven samples from two schools, which had both the tops and below ceiling sections of the columns sealed, had no asbestos fibres detected in the classroom air samples taken during normal use and occupation. A further 21 samples from five schools where the below ceiling column casings only were sealed, also had no asbestos fibres detected in the classroom air samples taken during normal use and occupation. However, TEM analysis of three samples taken in a school corridor between two sets of double swing doors did find one PCME amosite fibre. As the doors were mounted on the columns and were frequently opened and banged shut, causing movement and vibration to the building structure, this was a particularly active area. The pooled result from 3 samples gave a calculated concentration equivalent to the analytical sensitivity of 0.0001 f/ml and was below the limit of detection (0.0005 f/ml).

![Figure 9: TEM results of the PCME asbestos fibre concentrations in air before and after striking columns in reasonably good condition and slamming doors mounted on the column. All air concentrations given in terms of the calculated limit of detection (i.e. 95% confidence that concentrations are below this value). Asbestos fibres were only detected after hitting the column casings).](image)
3.8. TEM results for releases from columns in good condition
A CLASP school where columns were judged to be in reasonable / good condition was sampled before and then during and after peak release testing. The results in terms of PCME amosite fibres are summarised in figure 9. These results further add to the evidence based observation that airborne fibre releases from the columns to the room air, occur much more readily when there is substantial direct disturbance to the column casing and the casings have damage and/or gaps along the seams or edges in the room (i.e. below the ceiling void).

4. Discussion

4.1. Mechanisms for release of airborne fibres
Although asbestos is a hazardous carcinogen, a risk will occur only when the asbestos fibres in the material are made airborne, inhaled and deposited in the lung. Generally for fibres to be released from an asbestos containing material (ACM) to air, some form of disturbance is necessary. Disturbance due to maintenance activity is a recognised as a way of producing short-term “peak” exposure episodes and a specific duty to manage asbestos is present in the control of asbestos regulations (CAR, 2006) to minimise the possibility of uncontrolled maintenance releases. Direct disturbance and impact damage to ACMs by the building occupants will also result in short-term “peak” releases of fibres to air. Hence, the duty to manage also requires regular inspections for signs of damage or deterioration to the ACMs in the building, with appropriate management action being taken to minimise further damage and release, as far as reasonably practicable. If damage to ACMs occurs and the debris is not cleaned-up appropriately, there is the possibility that this may increase the background airborne fibre concentrations in the building, due to the dust and debris being disturbed and re-suspended by occupants and cleaning personnel.

Background concentrations due to environmental-related factors are usually several orders of magnitude lower than “peak” disturbance releases. Expansion and contraction of the building structure due to thermal changes, vibration, wind-pressure and air erosion and normal occupancy, have all been suggested as possible disturbances, which can cause fibre release and give raised background concentrations. Although a combination of these are usually present, the airborne fibre concentrations produced are rarely above the limit of quantification that a single sample measurement can realistically achieve. Conversely, short-term peak releases are measurable but occur relatively infrequently. This is why in this report extensive use of simulations and peak release testing were carried out to assess whether the remediation measures were effective in minimising airborne releases and could be applied with minimal disturbance and fibre release. It is important to distinguish that peak release testing does not represent the average exposure but may contribute to it.

The magnitude of any release of airborne asbestos fibres will depend on a range of release factors (e.g. type of ACM; the condition of the ACM, the type of disturbance taking place; the magnitude of the disturbance and force applied; the length of time the disturbance takes place; the surface area or volume of the ACM being disturbed) and on other mitigating factors (e.g. wet, enclosed, encapsulated; ventilation rates, distance the source of the release, etc). In particular, for the CLASP columns the amount of airborne fibre release depends on the integrity of the casing and the: presence of gaps and holes, visual damage and denting, looseness / amount of movement when pushed; maintenance work carried out after installation (e.g. fixtures attached to the casing or holes drilled into the casing) or improper installation (e.g. when new windows installed) etc. As most of these release factors can be assessed visually from inside the room inspection of the column casing and sealed by the use of silicone fillers and cover tapes this provides a simple strategy to detect and prevent airborne releases to the occupants.

4.2. Monitored releases from columns without remediation
The highest concentrations found from peak release testing in schools under the simulation conditions described and in a sealed area was 0.44 f/ml, next to the column. Higher airborne concentrations can
be released if the column is more damaged and hence less efficient in protecting the AIB and containing the release. AIB can be quite friable and can be damaged relatively easily giving rise to peak airborne fibre concentrations of a few f/ml. During poor dry removal where AIB ceiling tiles are broken and dropped to the ground airborne concentrations of well over 10 f/ml can be generated. Therefore there is a potential for higher fibre concentrations to be released if the casings are removed or detached. The highest value recorded to date (2.37 f/ml) during peak release testing was in a non-school situation, where the casing had become detached and was left dangling by a single screw at the top of the column. The higher levels of release possible once the casing is detached or removed, underlines the current requirement (see Reg 4 of CAR, 2006) for the management and the routine checking of all ACMs and any control measures (such as enclosures) for signs of damage.

A draft report (personal communication, 2008) [7] of some testing undertaken for publicity purposes in a school was also sent to HSE. As described the report appeared to have carried out far greater numbers of violent disturbances to the column casing and surrounds than used by other laboratories. The column was also described as having a gap down the front of the column. In addition, a small enclosure surrounded the column (<10 m$^3$) and the ceiling tiles had been taken down and disturbance was carried out around the top of the column. The comparative static samples collected over a period of one hour gave results of 0.72 and 0.49 f/ml, which given the intensity of the disturbance was consistent with the results summarised above.

4.3. Effectiveness of remediation

The focus of the work was not to carry out a survey to find the highest release from an unremediated column but to engineer and assess a suitable way to minimise the release of airborne fibres into the room where occupants are present. This assessment was carried out using the same peak release testing procedure. The results showed that by sealing any gaps in and around the casing that were visible in the room, was an effective way of reducing occupant exposure. The mean and median PCM fibre concentrations after sealing were 0.006 and 0.002 f/ml respectively, with the highest single result of 0.032 f/ml. When the top of the column was also sealed and the whole area cleaned before re-testing this gave a mean and median of 0.004 and 0.003 f/ml, respectively, with the highest result being 0.058 f/ml.

The requirement under regulation 11 of CAR, 2006 is to prevent exposure as far as reasonably practicable, or to reduce exposure to the lowest level reasonably practicable. Given that the PCM data from peak release tests had mean values no more than twice the limit of detection and ~95% of measurements were below the limit of quantification it is clear that exposures are as to close to as low as reasonably measurable by the PCM method. It is important to note that the PCM count does not discriminate between asbestos and non-asbestos fibres so the PCM count represents the maximum value for the asbestos fibre component. Peak release testing is not representative of the average asbestos exposures to the occupants as it is clearly meant to replicate an infrequent high release event to assess the efficacy of the controls.

To derive an estimate of the average asbestos exposure, longer sampling during normal occupation with analytical TEM analysis is necessary. When the TEM analysis was used to analyse 28 samples from seven schools, which had been re-occupied after remediation, no asbestos fibres were detected in the analysis of high volume samples collected inside classrooms. Most individual samples had analytical sensitivities of ~0.0002 f/ml and a limit of detection of ~ 0.0006 f/ml. Taken as a group representing occupied CLASP schools which had under gone remediation (two had complete remediation), an overall analytical sensitivity of 0.000016 f/ml was achieved and the average level in schools following remediation was below the limit of detection <0.000048 f/ml. This represents the upper 95% value for PCME asbestos fibres and is some ten times lower than the average background previously found in UK asbestos containing buildings (Burdett and Jaffrey, 1986). A single asbestos fibre found during the analysis of three samples taken between two sets of swing doors in a school corridor are included the calculated value for the asbestos concentration (and analytical sensitivity) was 0.000014 f/ml.
Although, prior to remediation, no measurements were made in schools containing AIB materials in the columns, five weeks of monitoring in an ex-school building now used as a busy office was carried out. This gave a calculated concentration for PCME asbestos fibres equal to the analytical sensitivity of 0.000005 f/ml and an upper 95% confidence value of <0.000024 f/ml for continuous daytime monitoring over the five-week period. It is notable that during one of the sampling periods a severe gale took place causing widespread damage across the country but no asbestos fibres were detected in the air samples taken over the period.

Often the casing may not extend directly to the roof space or the floor above and may finish above the suspended ceiling, leaving a few centimetres of the AIB projecting above the casing. Although the projecting part of the AIB is unlikely to be directly disturbed, the top of the column is unsealed and provides a possible route for airborne fibres to be released into the roof space / ceiling void. In many schools the level of interconnectivity and air change between the classroom and void areas is likely to be limited unless the ceiling tiles have been damaged and removed. The measurements carried out in occupied classrooms, where the tops had or had not been sealed, did not detect any significant difference in the fibre concentrations and the results of peak release tests at room level also showed no significant differences in the data available. However, monitoring in the ceiling void at some sites showed that exposures to workers who have to enter the ceiling voids to carry out this sealing may occur, while it is far from clear that there is any significant additional reduction to occupants, from sealing the tops of the columns. Also, the possibility for further spread of dust and debris into the classroom from work above the sealing remains as well as other risks such as working at height.

4.4. Comparison to other work

The average air concentrations measured in occupied classrooms after remediation (<0.00005) f/ml) and in the occupied office (0.00002 f/ml) before remediation were an order of magnitude lower than the average background found in other asbestos containing buildings [8,9] (i.e. 0.0005 f/ml Burdett and Jaffrey, 1986; 0.0004 f/ml HEI, 1991). A recent update of US asbestos containing buildings (Lee and Van Orden, 2008) reported the average PCME asbestos fibre concentrations in 317 occupied schools as 0.0001 f/ml and an average of 752 buildings as 0.00008 f/ml. The outdoor environment close to the buildings had an average concentration of 0.00002 f/ml. These averages were based on pooling relatively large numbers of samples e.g. 3979 samples for inside all buildings and 1678 outdoor samples). Although the types of asbestos and construction will differ and the results in this paper are based on far fewer samples, there is no significant difference between the US TEM results and those from the CLASP schools.

4.5. Exposure limits and measurement issues

Currently, the EU wide exposure limit for workers is based on an 8-hour time weighted exposure of 0.1 f/ml as counted by the WHO method [11] for light microscopy (WHO, 1997). The UK operates a tighter standard based on 0.1 f/ml monitored over a 4-hour period but also limits peak exposures to a maximum of 0.6 f/ml over a 10 minute sampling period. These are regarded as the upper limit and in general there is an expectation to reduce levels to as low as reasonably practicable through the use of appropriate controls. There are no EU or UK limits for environmental exposure but the WHO has recommended a limit of 0.001 f/ml based on the annual cumulative exposure. The UK clearance indicator, which is used to determine if it is appropriate to remove an enclosure after work on asbestos has been completed, is 0.01 f/ml. This is not a health based limit but a peak disturbance / clearance indicator to show that this level would unlikely to be exceed by any subsequent routine activity that is likely to occur.

The vast majority of static samples collected for PCM analysis, sampled 480 l of air on the filter and counted 200 fields of view. This gives a calculated limit of detection (LOD) of 0.003 f/ml based on there being a 95% confidence that the filter background counts do not exceed 5 fibres and any additional fibres were likely to be collected from the air. However due to the poor precision of counting low numbers of fibres, HSG 248 recommends that a LOQ for reporting individual samples of
0.010 f/ml (based on 20 fibre counts). As the purpose of this paper was to summarise many such counts, using the same sampling and analysis protocol, a more meaningful average could be obtained by reporting all individual measurements as their calculated values and taking the average of the individual results. If substantially different volumes of air or areas were analysed the samples were pooled together and the mean calculated by dividing the total numbers of fibres counted by the total volume of air analysed during the PCM count. Therefore although data were often initially reported as <0.01 f/ml, all values were recalculated and these individual values were used to calculate the mean. The range and distribution of the individual sample concentrations have also been given.

5. Conclusions
Direct impacts and flexing of the column casings which disturbed the AIB (especially when the AIB was directly attached to the casing) appeared to be the main mechanism for fibres to be disturbed and released inside the column. These fibres can then disperse directly into the room, through gaps or damage in the column casing or where it interfaces to other surfaces inside the room.

Peak release testing by banging the columns, slamming doors attached to or adjacent to columns as well as similar disturbance of window areas, was shown to give rise to airborne concentrations of PCM fibres, many of which were shown to be amosite fibres by TEM analysis of the PCM equivalent fibres.

Visual assessment of the column casing and its immediate surroundings below the ceiling level for gaps and damage is an important way of assessing whether peak releases may take place. The duty to manage in the control of asbestos regulations (CAR, 2006) already requires the duty holder in schools to make an assessment and carry out regular re-inspections for signs of damage or deterioration to the ACMs in the building. The duty holder also has to take appropriate management action to minimise and control damage and fibre release, as far as reasonably practicable.

The PCM fibre concentrations data from the peak release tests showed that while direct releases of fibres to the room air can occur from gaps and holes in and around the column casings, sealing is an effective way of minimising releases to below the limit of quantification (0.01 f/ml) of the PCM method for some 95% of the tests carried out. Sealing with silicone filler and taping gaps and seams on the column casing below ceiling also gave concentrations below the LOQ of the PCM method for 95% of the tests carried out. The data available did not show any significant difference between the PCM fibre concentrations in the room air for columns that had or had not been sealed in the ceiling void, as well as in the room.

Occupant exposures during normal teaching activities in areas that had undergone remediation were also monitored, with much greater use of TEM analysis to determine the asbestos fibre concentration. No asbestos fibres were found in the TEM analysis of samples of classroom air from eight schools, after remediation had taken place. Occupant exposures in only one school and one office building have been monitored before remediation, and only one asbestos fibre was found in each case. The average monitored occupant exposures to asbestos in CLASP buildings was <0.00005 f/ml an order of magnitude lower than previous measurements in UK buildings.

If sealing of the tops of the columns is to be undertaken, the additional disturbance and potential exposures of maintenance personnel, along with the risks from work at height, should be considered in the risk assessment.

Acknowledgements
To ensure all data available could be collected all participating local authorities, schools and laboratories were assured that the data would be presented in a non-attributable form. Therefore there are many people who have contributed to this data set and summary, whose help is gratefully acknowledged. The HSL results relied heavily on the support and efforts of HSL staff.
References
[1] Burdett, G.J. (2007) Summary of fibre concentrations in CLASP construction schools containing asbestos. http://www.hse.gov.uk/research/hsl_pdf/2007/hsl0722.pdf.
[2] Burdett, G. (2008) Further measurements of fibre concentrations in CLASP construction buildings. http://www.hse.gov.uk/research/rrhtm/rr624.htm
[3] HSG248, Asbestos: The analyst’s guide for sampling, analysis and clearance procedure, HSE 01/05; ISBN 0-7176-2875-2, 2005. Available from HSE Books.
[4] ISO 10312:1995. Ambient Air - Determination of asbestos fibres - direct transfer transmission electron microscopy procedure. International Standards Organisation. Geneva. 1995. Available from British Standards Institute, 389 Chiswick High Road, London W4 4AL
[5] BS EN ISO/IEC 17025:2000 General requirements for the competence of testing and calibration laboratories. Available from British Standards Institute, 389 Chiswick High Road, London W4 4AL
[6] CAR, Control of Asbestos Regulations, SI 2006/2739 The Stationary Office, ISBN 0 11 075191 4, 2006.
[7] Personal communication (from Johnathon Gibson, ITN Ltd. Draft report by G & L Consultancy, Taunton, Somerset, TA3 5PX)
[8] Burdett, G.J.; Jaffrey, S.A.M.T. (1986) Airborne asbestos concentrations in buildings, Annals of Occupational Hygiene, 30, 2, 185-199.
[9] Health Effects Institute - Asbestos Research, Asbestos in public and commercial buildings: A literature review and synthesis of current knowledge. 1991.
[10] Lee, R.J. and Van Orden, D.R. (2008) Airborne asbestos in buildings. Reg. Tox. and Pharm., 50, 218-225.
[11] WHO, Determination of airborne fibre number concentration. A recommended method by phase-contrast optical microscopy (membrane filter method). World Health Organisation, Geneva. 1997.
| Statistic                              | Peak release testing of columns before remediation | Peak release testing of columns after remediation | Peak release testing of columns after sealing columns in room only. | After remedial work before occupation | Normal occupation after remedial work | Exposure during sealing and taping columns in the room and ceiling | Exposure during sealing and taping columns in the room | Inspection of ceiling area |
|---------------------------------------|---------------------------------------------------|--------------------------------------------------|-------------------------------------------------------------------|--------------------------------------|--------------------------------------|-----------------------------------------------------------------|-----------------------------------------------------------------|---------------------------|
| Number of samples                     | 31                                                | 95                                               | 14                                                                | 44                                   | 96                                   | 12                                              | 188                                             | 20                        |
| Mean (f/ml)                           | 0.094                                             | 0.004                                            | 0.006                                                             | 0.002                                | 0.005                                | 0.004                                          | 0.002                                           | 0.004                     |
| Median (f/ml)                         | 0.033                                             | 0.003                                            | 0.003                                                             | 0.001                                | 0.004                                | 0.004                                          | 0.002                                           | 0.002                     |
| Largest value (f/ml)                  | 0.441                                             | 0.058                                            | 0.032                                                             | 0.008                                | 0.022                                | 0.006                                          | 0.039                                           | 0.019                     |
| Smallest value (f/ml)                 | 0.001                                             | <0.001                                           | 0.001                                                             | <0.001                               | 0.001                                | 0.001                                          | 0                                              | 0                         |
Table 2: PCM results from peak release testing before and after remediation and while partially sealing the column with minor gaps.

| Room number and sample position                                                                 | PCM fibre concentration (f/ml) |
|-------------------------------------------------------------------------------------------------|-------------------------------|
| Class 43 adjacent to undamaged column during and following striking of the column.              | 0.07                          |
| Class 43 teachers position (corridor end) during and following striking of the column.          | 0.03                          |
| Adjacent fixed point sample while sealing up column in room 43.partial remediation.             | 0.006                         |
| Adjacent fixed point sample, during and following the striking of column after partial remediation | 0.010                         |

Table 3: Results from peak release testing of column casings in good condition before and after full remediation at room levels and in the ceiling void.

| Sample position                            | PCM fibre concentration (f/ml) |
|--------------------------------------------|-------------------------------|
|                                            | Before remediation in room    | After remediation in room    | Before remediation in ceiling void | After remediation in ceiling void |
| Corridor outside HM office                 | 0.005                         | 0.008                        | 0.005                             | 0.013                             |
| Staff room adjacent to windows             | 0.007                         | 0.025, 0.031                | 0.022                             | 0.347                             |
| Room opposite HM office                    | 0.012                         | 0.006                        | 0.007                             | 0.024                             |

Table 4: Results from simulated maintenance activity using personal sampling from schools considered to have potential high amount of AIB contamination in ceiling areas.

| Simulated maintenance activity                            | PCM fibre concentration (f/ml) |
|-----------------------------------------------------------|-------------------------------|
| Ceiling void inspection 14 tiles lifted in staff room.    | 0.012, 0.022                  |
| In ceiling void of staff room shaking and moving cables   | 0.023                         |
| Static samples in room below disturbed area               | 0.007, 0.002                  |
| Brushing in ceiling void of staff room (5 minutes brushing) 10 minutes sampling | 0.18                          |
| Brushing in ceiling void of lobby (1.5 minutes brushing) 10 minutes sampling                      | 0.18                          |
| Lifting tiles in kitchen area and disturbing cables (different school)                              | 0.011, 0.029                  |

Note: air extraction on