The effectiveness of witnessed four-stage clearances following licensed asbestos removal

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The importation and use of asbestos in Great Britain (GB) was banned by 1999. However, asbestos can be present in buildings constructed or refurbished before 2000 and continues to be removed as part of ongoing risk management. Only HSE licensed asbestos removal contractors (LARCs) can undertake higher-risk removal work. Confirmation that the area can be reoccupied is undertaken by accredited 4-Stage Clearance (4SC) organisations. This research aimed to assess whether standards had improved and whether there was compliance with HSE guidance (HSG248, 2005 version) during 4SC. HSE researchers observed work practices of 4SC analysts at eight licensed asbestos removal sites and collected air monitoring samples, between 2016 – 2019. As the findings below represent work under HSE observation they may not be representative of unobserved practice:

- **certificates for reoccupation (CfR), were issued at all sites but were not always clear, unambiguous and accurate.**
- **industry integration of HSE recommendations from previous work (HSE 2018) was observed at five sites.**
- **an improvement in the application of the 4SC process was observed compared to previous studies (more failures were correctly identified).**
- **reassurance air monitoring carried out by HSE scientists after stage 3 had elevated fibre concentrations. This is optional in guidance and was not conducted by any 4SC analysts.**
- **HSE guidance (HSG248) was not always followed:**
  - **when selecting and using Respiratory Protective Equipment (RPE).**
  - **when LARCs were required to undertake additional cleaning (analysts remained in the enclosure).**
  - **when undertaking dust disturbance activities.**

These findings will help to inform HSE’s intervention approach.

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The effectiveness of witnessed four-stage clearances following licensed asbestos removal

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Research Ethics Statement

Ethical approval for this study was given by the University of Sheffield Medical School Research Ethics Committee [HSL19, approved 14.04.2019].

Key Messages

The requirements of the Control of Asbestos Regulations (CAR) 2012 (CAR 2012) are designed to prevent or minimise exposure to asbestos. Where those employing asbestos removal workers comply with the detailed requirements and guidance in the Managing and working with asbestos, Control of Asbestos Regulations 2012 - Approved Code of Practice (ACOP) and other associated guidance, they will be protecting their workers so far as is reasonably practicable.

The aims of this research were to:

- assess whether the methodology used by four stage clearance (4SC) analysts during the 4SC process, including communications with the Licensed Asbestos Removal Contractors (LARCs), have improved; and
- provide a measure of the extent to which industry practice now complied with HSE guidance (HSG 248), since HSE's work on the Asbestos Analyst Inspection Program, 2015 (HSE 2018).

HSE scientists visited eight removal sites between 2016-2019 observing work practices and control measures used throughout 4SC. The sites included the most frequently removed licensed asbestos materials, including asbestos insulating board (AIB) and asbestos pipe insulation. This research focusses on 4SC conducted after completion of each licensed asbestos removal site. The 4SC is undertaken by independent accredited (ISO/IEC17025;2017) analytical organisations to check that the clients' requirements were met, and the area is suitable for reoccupation. A certificate for reoccupation (CfR) is issued to confirm this.

Some improvements in the application of the 4SC process have been observed compared to previous studies (more failures were correctly identified), and industry integration of HSE recommendations from the Asbestos Analyst Inspection Program, 2015 (HSE 2018) were evidenced by the introduction of handover paperwork from the LARC to the 4SC analyst (this was observed at five sites).

However, some issues previously identified (HSE, 2018) were still observed:

- CfRs were issued for all sites but were not always clear, unambiguous and accurate. A CfR enables dutyholders to fulfil legal obligations for managing asbestos and provides evidence of removal of asbestos containing materials (ACMs).
- after Stage 3, HSE testing identified that airborne fibre levels were elevated at two sites, during or after enclosure dismantling. Reassurance air monitoring, optional in HSG248 guidance, was not conducted by 4SC analysts.
- HSE guidance was not always followed by 4SC analysts in the following areas:
    - When selecting and using Respiratory Protective Equipment (RPE).
    - When LARCs were required to undertake additional cleaning, analysts remained in the enclosure.
    - When undertaking dust disturbance activities.

Executive Summary

Background

The Control of Asbestos Regulations (CAR) 2012 (CAR 2012) are designed to prevent or minimise exposure to asbestos by ensuring that asbestos containing materials (ACMs) remaining in buildings and premises are properly managed and maintained.

Asbestos removal which requires a licence under CAR 2012 is defined as work which is not 'sporadic and low intensity' and where it cannot be clearly demonstrated by risk assessment that the control limit (0.1 fibres per millilitre (f/ml) of air averaged over four hours) will not be exceeded. Removal work that is identified as likely to exceed the control limit includes work on surface coatings (excluding textured decorative coatings), asbestos insulation or asbestos insulating board (AIB).

CAR 2012 Regulation 17 guidance in the ACOP (L143, HSE 2013a) requires all licensed asbestos removal projects to be followed by a 4SC conducted by an independent organisation accredited to ISO/IEC17025. A CfR is issued when all stages are deemed to have passed. The 4SC consists of:

- stage 1 - Preliminary check of site condition and job completeness.
- stage 2 – Thorough visual inspection.
- stage 3 – Clearance indicator air sampling for airborne fibres.
- stage 4 – Final assessment post-enclosure and dismantling of work area.

Aims

The aims of this research were:

- to assess whether the methodology used by 4SC analysts during the 4SC process, including communications with the LARCs, have improved; and
- to provide a measure of the extent to which industry practice complied with HSE guidance HSG248, since HSE's work on the Asbestos Analyst Inspection Program, 2015 (HSE 2018).

Method

HSE scientists visited eight sites between 2016 - 2019, with seven different analytical companies represented. The 4SC analysts were employed directly by the client in all but one case and were informed in advance of the HSE site visits. Project information sheets were supplied to each company supplying the 4SC analyst. Each stage of the 4SC was observed by HSE scientists: in addition, HSE scientists undertook air sampling during the 4SC process with parallel air sampling for Stage 3 and reassurance air sampling during enclosure dismantling. HSE scientists did not complete their own visual inspections immediately after the area was passed by the 4SC analyst as this would have interrupted the flow of the work which was being assessed.

Airborne fibre concentrations were measured using sampling pumps to draw air through a known filter area. After sampling, each filter was cut in half, with one half cleared using the acetone / triacetin method for analysis by Phase Contrast Microscopy (PCM). The other half was retained for potential analysis by Transmission Electron Microscopy (TEM). Fibre counting by PCM was undertaken using World Health Organisation (WHO 1997) fibre counting rules, as described in HSG 248 (HSE 2005). Selected half filters were prepared and counted by TEM following ISO10312 (ISO 1995). At least one sample per site was selected for TEM analysis.

Findings

The 4SC process was assessed on all sites visited. There was clear evidence that the LARC and 4SC analyst had co-operated during planning of the work. For each site, the same 4SC company was employed during the lifetime of the individual removal project. This minimised the likelihood of a negative impact from using multiple analysts and / or analytical companies, an observation that had been identified in the Asbestos Analyst Inspection Program (HSE 2018). More 4SC analysts were drafted in to assist when Stage 2 visual inspections and Stage 3 clearance air monitoring of larger enclosures was required. The 4SC analysts conducting work on-site understood their roles and no incidents relating to impartiality or coercion were witnessed.

Stage 1: The Stage 1 inspections were completed in a systematic manner and all areas identified in HSG 248 (HSE 2005, was in use for these site visits) were checked as part of the process. All hygiene units were checked and found to be fit for purpose at Stage 1.

Stage 2: The duration of the visual inspections broadly matched the examples in the HSG 248 guidance (HSE 2021, second edition) based upon the complexity and size of the enclosures. Whenever Stage 2 visual inspections failed, the reasons were recorded by the 4SC analyst and were clearly communicated to the LARC. The Stage 2 visual inspection failure rate was higher than that previously reported, via internal communications with the United Kingdom Accreditation Service (UKAS), with 36% (4 out of 11) of enclosures failing this stage. The 4SC analysts conducting the visual inspections did not conduct any activity that would be deemed as asbestos removal as described in HSE’s Asbestos Analyst Program. However, in some cases, the 4SC analyst did remain inside the enclosure whilst minor cleaning was undertaken by the LARC. The RPE worn by the 4SC analyst was either re-usable ori-nasal (half mask) or full-face power assisted. Ori-nasal RPE was worn for over an hour on four separate occasions, which is contrary to HSE’s guidance limits in HSG 53 (HSE 2013b).

Stage 3: Air sampling with dust disturbance (by brushing) was conducted, with at least the minimum number of sampling points, as detailed in HSG 248, being collected. The sampling point placements were appropriate with all areas of the enclosures being adequately covered. Stage 3 failed for three enclosures with one (Spray Coating enclosure) failing four times. The brushing activity was not always conducted for the minimum time detailed in HSG 248 guidance and in one case a 4SC analyst used a plastic waste bag for the disturbance rather than a brush or broom, contrary to ACoP L143 paragraph 450 (HSE 2013a). On one site, there was a difference in the clearance fibre counting results between the HSE scientists and the on-site 4SC analyst. The HSE scientists' results indicated that the clearance air test results were above the 0.01 f/ml clearance indicator and the 4SC analysts' results were marginally below 0.01 f/ml. When made aware of this, the decision was made by the 4SC analyst, with agreement of the LARC Supervisor, to fail Stage 3 and to request that the enclosure was re-cleaned and re-tested.

Stage 4: The Stage 4 inspections were completed according to HSE guidance. One area identified for improvement was ensuring that the LARCs equipment was cleaned and bagged if required, before being taken out of the enclosure. HSE Air monitoring results at this stage indicated elevated levels of airborne fibres that were above the clearance indicator on some sites. However, not all 4SC analyst companies conducted reassurance air testing at Stage 4 that would capture this fact.

A selection of CfRs (the formal record detailing the conclusions of the 4SC process) were examined to ensure that they were accurate reflections of the site activities. These were found to be mainly accurate, but inconsistencies were identified in areas such as drawings, recording of the duration of the visual inspection and results. The CfR is essential for the duty holder to understand what asbestos has been fully removed and where it may still be present. The CfRs therefore need to be clear and unambiguous, and this was not always the case.

Contents

1 Introduction

1.1 Background

CAR 2012 (CAR 2012) places a requirement on dutyholders of non-domestic premises to manage asbestos in their properties by identifying where it is present and monitoring its condition. Where ACMs are in poor condition they should be removed, repaired or encapsulated. Where any building is undergoing major refurbishment or demolition, ACMs should be removed unless removal would cause a greater risk to employees than if the asbestos had been left in place.

An important part of the process of asbestos removal is ensuring that the ACM has been removed as far as is reasonably practicable before the area is reoccupied, refurbished, or demolished. The Approved Code of Practice (ACoP), Managing and Working with Asbestos, L143 (HSE 2013a) outlines the measures that should be taken when working with asbestos, including removal work. Licenced work with asbestos normally involves an enclosure which is a temporary polythene sheeted area, constructed over a wooden framework with an airlock and baglock system. The ACoP sets out the 4SC process that must be followed before the enclosure is removed and the area can be re-occupied. The four stages of this procedure are:

- **stage one:** An initial inspection of site conditions and job completeness.
- **stage two:** A thorough visual inspection inside the enclosure to ensure it is free of dust and debris.
- **stage three:** Brushed disturbance air tests which, at the time of this study, 80% of results had to be below the clearance indicator of 0.01 f/ml, for them to pass (HSE 2005).
- **stage four:** A final visual inspection of the work area following the dismantling of the temporary enclosure, to ensure that there is no visible ACM debris.

More detailed working procedures for asbestos removal and assessment for reoccupation of areas after removal are given in HSE guidance HSG247 Asbestos: The Licensed Contractors' Guide (HSE 2006) and HSG248 Asbestos: The Analysts' Guide (HSE 2021). Clearances of decontamination units were not covered in this research because sites were still live when the HSE scientists finished the agreed scope of the research project. Some of the guidance in HSG247 was based on earlier HSE research which looked at the exposures of removal workers during wet stripping of ACMs (Burdett 1998). The aim of the HSG247 guidance is to reduce removal worker exposure and airborne fibre levels more generally.

A survey and inspection programme of some 4SC analytical companies work was carried out by HSE Field Operations Division (FOD) in 2015 (HSE 2018). It is a requirement of CAR 2012 that analytical companies that carry out the 4SC procedure must be accredited to the ISO/IEC17025:2017 standard (this also includes aspects of ISO/IEC17020:2012 for the visual inspection stages). In the UK, the sole accreditation body in this field is UKAS. This programme involved sending out a questionnaire to all UKAS accredited asbestos laboratories, conducting interviews at a small selection of head offices, and carrying out on-site inspections following those interviews. The inspection programme report set out the responses from 4SC analytical companies and the observations of HSE Inspectors. These responses and observations gave HSE an overview of how 4SC analytical companies were applying guidance.

1.2 Project setup

The 4SC procedure represents an important part of the removal process to ensure removal works have been carried out to the client's (or dutyholder's) specification and asbestos has been removed as far as is reasonably practicable. These aims were achieved by visiting eight sites throughout the whole removal process from enclosure construction to the dismantling of the enclosure after the 4SC procedure. A range of measurements, including static and personal air monitoring samples were collected, together with direct observations of work practices, supported by Closed Circuit Television (CCTV) recordings inside asbestos removal enclosures during removal activities. HSE scientists did not conduct Stage 2 visual inspections themselves after the 4SC analysts as this could have potentially biased the process. Visual inspection methodologies and any areas for improvement observed were noted by HSE scientists.

This report focuses on the observed work practices and air monitoring obtained during the 4SC procedures from the eight site visits. All visits were carried out between 2016 – 2019 and followed the guidance in HSG 248 (HSE 2005). Although an assessment of the 4SC procedure witnessed on the participating sites was performed, this did not represent a formal comparison with the supporting guidance. The scope of this study did not include an ongoing assessment of site conditions after the 4SC was completed.

All LARCs that took part in this project, did so voluntarily. The research proposal was approved by an independent ethics committee as detailed in the acknowledgements of this report. Individual removal workers were able to opt out, even if the LARC had agreed to participate. However, individual 4SC analytical companies were not volunteers, they were employed directly by the client or dutyholder and their identity was often not known until HSE scientists arrived on site. Whenever their identity was known, they were informed of visits in advance and provided with project information sheets. These were published earlier in HSE Research Report 1176 (HSE 2022) and explained how the 4SC would be observed and that parallel clearance air tests would be taken by HSE scientists. 4SC analysts on-site during the visits had the option to consent to wearing personal monitoring pumps.

HSE scientists selected the sites from the work the volunteer LARCs were carrying out. LARCs, and where possible 4SC analytical companies, were informed in advance that the objective of the research work was to observe and monitor the various site activities.

2 Methods

2.1 Selection of volunteer companies and asbestos removal sites

The process for the engagement of the LARC volunteers has been described in HSE Research Report RR1176 (HSE 2022). Once a suitable site was identified, the LARC was approached, so that an agreement for HSE scientists to visit could be made (unless the site had been specifically put forward by the LARC, as was the case for one site). Only one LARC refused to let HSE scientists visit at this point, saying they did not feel the site was suitable as it was too small to accommodate both the required number of removal workers and HSE scientists. No suitable sites were identified for this LARC during the remainder of this project.

Once agreement had been made to visit the site, where possible HSE scientists contacted the analytical company to inform them they would be visiting.

Later in the project, jobs two weeks or longer were included to ensure that a greater volume of samples could be taken and so that the removal of sprayed coating could be included. Sprayed coating jobs are more complex and generally take longer than a week.

The recruitment of LARCs and sites was significantly more difficult than anticipated, with only a relatively small number of LARCs volunteering to take part initially. This resulted in only a small number of HSE notifications to monitor. Eleven LARCs volunteered after receiving information about the project and only five were subsequently included in the project. In the original project plan, it was anticipated that there would be a two-month gap between site visits. However, the difficulties in recruiting LARCs and selecting sites resulted in a gap of six months, on average, between visits.

For Sites 6, 7 and 8, the target ACMs were thermal insulation and sprayed coating. However, the volunteer LARCs did not have work of this type within the time constraints of the project. Therefore, a slightly different approach was taken and HSE’s licensed asbestos notification database was monitored for all jobs where these types of material were being removed. When suitable jobs were identified, the LARC was contacted and asked whether they would be happy to participate in the project. A total of ten LARCs were contacted in this way, with five responding positively. One agreed to a visit at the site suggested and four said they would be happy for HSE to visit a different site, either because they felt the chosen site was not suitable or there was not enough time to arrange a visit before the scheduled end of that job.

Consideration was also given to the type and size of volunteer LARCs with a view to observing a range of different companies. However, whilst a range of companies did take part, the small number of LARCs that volunteered meant that the priority was whether the material being removed was suitable for the project. A description of each of the sites and associated LARC is given in Table 1 below.

The analytical companies observed during the 4SC process were employed by the client in all but one case and did not have an option to volunteer as they were already contracted to do the work where HSE attendance had been agreed to. On the one site where the 4SC analyst was employed by the LARC, a different analytical company attended site than the one described in the plan of work supplied to the HSE scientists. The different analytical companies were informed in advance of the HSE site visit, where possible, and sent information sheets about the project, these were published in HSE Research Report RR1176 (HSE 2022).

Table 1 Description of the volunteer LARCs and the sites visited

Site visit Number	LARC description	Material type and amount being removed	Type of building (occupied or not)
1	Asbestos Removal Contractors Association (ARCA) member based in the northwest of England	Asbestos insulating board (AIB) door headers and boxwork - 8 m^2	University building basement (occupied, for refurbishment)
2	Asbestos Control and Abatement Division (ACAD) member with offices across the UK	AIB debris - 12 m^2 (Estimated area of contamination identified in survey)	Post office (unoccupied, for refurbishment)
3	National Federation of Demolition Contractors (NFDC) and ARCA member based in the East of England	AIB partition walls - 16 m^2	Office (unoccupied, for demolition)
4	ARCA and ACAD member based in the northwest of England	AIB casing to steel columns - 6 m^2	Factory (unoccupied, for demolition)
5	ARCA member based in Essex	AIB Ceiling - 50 m^2	Shopping centre (unoccupied, for refurbishment)
6	LARC based in Essex. Not a trade association member	Sprayed - coating to steel beams 80 linear metres	Office (occupied, for refurbishment)
7	NFDC and ARCA member offices across the UK	Insulation debris - (unknown quantity of debris in three risers and	University laboratory (unoccupied, for demolition)

Site visit Number	LARC description	Material type and amount being removed	Type of building (occupied or not)
		behind two radiator housings)	
8	NFDC and ARCA member based in the Northeast of England	Pipe Insulation -1 linear metre and debris in 5 linear metres of ducts	University accommodation (unoccupied, for demolition)

A 4SC analytical company was present on all sites; their activities included carrying out air monitoring during the removal work and the 4SC procedure at the end of the removal work. This sampling was independent of any air monitoring undertaken by HSE scientists.

There was normally at least one employee from the 4SC analytical company on site and occasionally where the project required, two or three were present. These employees were invited to volunteer to be included in HSE’s personal sampling regime for this project and to wear personal sampling equipment during their work inside the enclosure. In this report they are referred to as the 4SC analyst.

2.2 Overview of work on site

Two HSE scientists were present for each site visit. In most cases, the visit covered the beginning of work, enclosure construction, asbestos removal, the 4SC by an independent analyst and up until the enclosure had been dismantled. Static air monitoring was carried out throughout the site visit to assess airborne fibre levels during all aspects of the work. In most cases, personal monitoring was undertaken for all work activities, and work practices were observed or recorded on CCTV. The Negative Pressure Unit’s (NPUs) were used on or in enclosures to keep them under slight negative pressure, provide a flow of fresh air and to filter out any asbestos fibres prior to releasing the air to the external atmosphere.

The duration of each part of the 4SC varied from site to site and for some sites there was more than one enclosure, therefore the process was repeated more than once. For enclosure work, removal workers generally worked in two shifts, one in the morning and one in the afternoon with a break in between. The shifts varied in length from one to four hours depending on the site and the type of work being carried out.

Most air samples collected by HSE scientists were analysed on site using PCM. All filters were cut in half before being analysed so that further analysis by TEM could be performed as required to determine the actual asbestos fibre concentration. HSE scientists observed all aspects of the work, with all observations recorded in site notebooks and sampling sheets.

Documentation for each site visit, including risk assessments and plans of work were normally obtained from the LARC in advance of the site visit. This allowed HSE scientists to understand the planned approach. Work inside the enclosure was monitored and recorded using CCTV cameras and viewing panels. Cameras were set up during enclosure construction and then decontaminated as part of the 4SC procedure before being used on the next site.

Figure 1. An asbestos removal enclosure with airlocks being constructed on a site visited by HSE scientists

2.3 Sampling methods

2.3.1 Air sampling

HSE scientists carried out personal and static sampling using low-flow personal and high-flow static air sampling pumps, as appropriate. The sampling was carried out in accordance with HSE guidance set out in HSG248 (HSE 2005). The flowrate for each sample was selected to obtain as large a sample volume as possible without overloading the filter with dust. Where possible, personal samples were taken over the whole duration of a shift. On some sites the removal work created an unexpected level of dust and some filters were overloaded. When this occurred, flowrates were reduced for subsequent shifts. Details and results of all air monitoring samples can be found in HSE Research Report RR1176 (HSE 2022).

Figure 2. An asbestos removal worker wearing a sampling pump whilst removing waste from an enclosure

The flowrate, duration and volume of air were recorded for each sample taken. For personal samples, the name of the worker, the activity being carried out and the type of respiratory protective equipment (RPE) used were also recorded. In this report, workers names are not used. For static samples, the location and type of sampling (eg background, leak, reassurance) were recorded. The results were recorded in-line with HSE guidance and recorded in f/ml. The clearance indicator limit of <0.010 f/ml was used at Stage 3 of the 4SC procedure. The airborne clearance indicator is not an acceptable permanent environmental level. It is an indicator of site cleanliness before the enclosure is removed. Complying with the airborne clearance indicator threshold does not mean the area is completely free of airborne asbestos. Due to the very fine nature of asbestos fibres, some fibres may remain in the air for a period following any asbestos removal. Airborne fibre levels will reduce to natural background concentrations over time due to dilution, dispersion and settlement. The clearance threshold specifies a maximum acceptable limit for airborne fibre levels following asbestos removal. Further disturbance of any surfaces following dismantling of the enclosure should produce much lower fibre levels. The absence of any visible dust or debris, as confirmed in Stages 2 and 4 respectively of the clearance process, will make sure that there are no further sources available to generate airborne asbestos fibres (HSE 2021).

Reference is also made to the control limit for asbestos of 0.1 f/ml. The control limit means a concentration of asbestos in the atmosphere when measured in accordance with the 1997 WHO recommended method, or by a method giving equivalent results to that method approved by HSE, of 0.1 f/ml of air averaged over a continuous period of four hours.

On Site 5, removal workers wore two personal sampling pumps during removal work, to test the feasibility of wearing two sampling pumps at the same time, so that samples could be pooled and thereby improve the analytical sensitivity. The two pumps, tubes and cowls were attached to high-vis vests with cable ties. If the vests were worn inside the enclosure, they were removed on exit from the enclosure and disposed of as asbestos waste. The pumps, tubes and cowls were detached from the vest and decontaminated in the airlocks, as was the case for all personal sampling inside the enclosure.

2.4 Analysis methods

2.4.1 Phase Contrast Microscopy analysis

For all air monitoring samples (personal and static), membrane filters were analysed first by PCM. Filters were cut in half, with one half cleared and mounted on a microscope slide for PCM analysis in accordance with the method described in HSG 248. All visible fibres (>5 µm long and <3 µm wide with an aspect ratio of >3:1) were counted using the WHO counting rules. PCM cannot detect fibres with diameters less than 0.2 µm and the method does not allow discrimination between fibre types. The majority of PCM samples were counted on site. Quality control (QC) checks were carried out on a selected number of samples after the site visit. Results were reported as less than the limit of quantification (LOQ) where appropriate. The other filter half was stored for analysis by TEM (only selected filter halves were analysed).

2.4.2 Transmission Electron Microscopy analysis

Selected half filters from the air samples were analysed by TEM to cover all types of work activity undertaken. Samples were selected after each site visit by an HSE scientist who had knowledge of the site and work activities undertaken, ie low or high risk. The number of fibres counted by PCM and their morphology were also considered. Samples taken outside the enclosure were also chosen to confirm whether measurable asbestos fibre concentrations were present outside the enclosure.

The TEM method was based on the identification and fibre classification procedure set out for asbestos analysis in the International Standards Organization method ISO 10312:1995 (this was the version in use when the samples were analysed). At least two TEM sample grids were prepared and analysed for each filter sample. An appropriate number of TEM sample grid openings were searched at X5000 magnification to achieve an analytical sensitivity of <0.001f/ml. ISO 10312 uses the term ‘fibrous structures’ which includes a fibre, or connected grouping of fibres, with or without other particles (ie fibres, bundles, clusters and matrices of fibres).

All fibres with length >5µm and with morphology consistent with amphibole or chrysotile asbestos were measured (length, width, and aspect ratio) to determine whether they were phase contrast microscopy equivalent (PCME) fibres (ie fibres >5.0 µm long, 0.2-3 µm width and with an aspect ratio > 3:1 and therefore visible under PCM). For samples where three or fewer fibres were counted, the result was considered below the limit of detection (LoD) and the results were reported using ISO/IEC10312:1995 conventions.

The analytical sensitivity is a measure of how well the method can resolve the difference between two fibre concentrations. It is measured in f/ml and is calculated using the sample volume, the number of TEM grid openings examined, the area of filter analysed and the total filter area.

3 Results

3.1 Introduction to results

This section presents results from sampling and analysis carried out during the eight site visits.

Results include 4SC details, the enclosure size on each site, the duration of the visual inspection and the number of 4SC failures, either at the visual inspection (Stage 2) stage or the disturbance air test, Stage 3 (See section 3.3 and Table 2). For parallel clearance sample results (undertaken by the 4SC analyst and HSE scientists), the site and enclosure numbers are given in the results tables in Section 3.7. Enclosure diagrams for each site, showing detailed sample locations are given in Appendix A.

Samples analysed by PCM and TEM are presented as summaries in Sections 3.4 - 3.7 and Tables 3 - 12. Given the high number of samples taken, this was considered the most appropriate way to represent the results. For personal monitoring, only the sample duration, location and activity are reported, individual's names are not given.

TEM analysis results give the asbestos fibre concentrations as well as asbestos fibre numbers and type. If there is no column in a results table for a particular asbestos fibre type it means no fibres of this type were detected during the analysis.

3.2 Types of samples taken across sites

This report focuses on static air tests as part of the 4SC process and associated personal air tests at various stages. The static samples are divided into types, based on where and why they were taken during the site visit:

- 'parallel clearance samples', taken by HSE scientists alongside the 4SC analysts' samples.
- 'leak tests' conducted external to the enclosure whilst removal work was taking place inside the enclosure.
- 'enclosure dismantling samples were taken as the enclosure was dismantled after the Stage 3 of the 4SC had passed.
- post enclosure removal reassurance air testing was also undertaken sporadically for up to 14 days after the removal operation and 4SC had been completed for enclosure 1 on Site 6.

Personal samples are identified by the work activity that was being carried out when the sample was taken:

- 'enclosure dismantling' refers to all activities associated with dismantling the enclosure following the passing of the visual inspection and clearance air tests carried out as part of the 4SC.

- ‘personal monitoring’ refers to samples worn by 4SC analysts during Stage 2 visual inspections.

The ACM type that was being removed from each site is also given. Small scale AIB removal is defined as being less than 5 m^2 of AIB.

3.3 Summary of enclosure size and 4SC procedure

Table 2 in Section 3.7 describes each enclosure area, the number of Stage 2 visual inspections and their duration, brushing time, the number of Stage 3 air samples taken and if this stage failed. Notes are supplied for clarification with more details in the sections below.

3.4 Summary of PCM and TEM results from parallel clearance tests

Table 3 in section 3.7 below displays HSE scientists results for the clearance air tests that were taken at the same time as the 4SC analysts and that were subject to the same brushing and air disturbance regime. The HSE scientists' results agreed with the 4SC analyst results in all but one case (Site 1). The results show that there were Stage 3 measurements above the clearance indicator of 0.01 f/ml on 4 sites. On Site 1, the 4SC analyst initially recorded a measurement of <0.01 f/ml (indicating that Stage 3 had passed), but the HSE scientists’ counts from samples taken at the same time were >0.01f/ml (indicating that Stage 3 had failed). The 4SC analyst recounted their slide and issued a CfR which confirmed that Stage 3 had failed.

On Site 3, all three air tests results measured by the 4SC analysts were >0.01 f/ml and a CfR with failure at Stage 3 was issued. The area was recleaned by the LARC, re-tested and Stage 3 passed on the second attempt. For Site 5, there was one result at 0.011 f/ml and four <0.01 f/ml. This clearance passed due to 80% of results being <0.015 f/ml, as per HSG 248 at the time. Two sets of clearance air tests undertaken by the 4SC analyst failed on Site 6, whilst the HSE scientists were present. Three further sets of clearance air tests were taken by the 4SC analyst with each set of results gradually reducing after each re-clean until the area passed Stage 3 on the fifth set of clearance air tests. These results are discussed in Section 4.2.4 of this report.

Table 4 gives details of the TEM analysis results from the selected parallel clearance samples alongside the results from the PCM analysis of the same filter. Some differences in results between TEM and PCM were observed. For example, the TEM analysis gave higher fibre concentrations in nine out of twenty-four measurements for Sites 3, 5 and 6. These differences are discussed in more detail in Section 4.2.4.

3.5 Summary of PCM results for personal and static samples taken during enclosure dismantling

Tables 5 and 6 in Section 3.7 below, present the PCM results from static and personal monitoring samples taken during enclosure dismantling. Table 5 includes details of the asbestos material, location and activity undertaken. Elevated reassurance air testing results at Stage 4 were recorded for Sites 1 and 8. This is discussed in more detail in Section 4.2.5.

The PCM results from static monitoring carried out on Site 6, enclosure 1 are presented in Table 7. The samples were taken after completion of a large 4SC that was not witnessed by HSE scientists. However, enclosure 1 was dismantled whilst enclosure 2 was being constructed, so the opportunity was taken to conduct air monitoring during this activity and the period afterwards. TEM results for these samples are given in Table 10 and the results are discussed in Section 4.5.

3.6 Summary of TEM results for personal and static samples taken during enclosure dismantling

Tables 8 and 9 in Section 3.7 present the TEM results from static and personal monitoring samples taken during enclosure dismantling. The tables include sampling information, PCM fibre concentrations, TEM fibre concentrations and details of fibres counted.

Table 10 displays the TEM results from static monitoring carried out on Site 6, where enclosure 1 had been located, following a 4SC that was not part of the witnessed programme. The sample volumes were very high and asbestos fibres were present at low levels following the clearance. No specific reason could be readily identified for the fluctuations in the airborne fibre levels measured in the area after the enclosure removal and issue of the CfR.

Table 11 gives details of the PCM analysis for personal monitoring samples worn by 4SC analysts during Stage 2 visual inspections. The asbestos material type and activity being undertaken during the personal sampling are also given. These results are discussed in Section 4.5.

Table 12 has the TEM results of selected personal air monitoring samples from 4SC analysts conducting visual inspections. These are discussed in Section 4.5.

3.7 Tables and figures relating to Sections 3.3 to 3.7

Table 2 Enclosure size and details about each 4SC procedure

Site/Enclosure	Enclosure size including airlock & baglock (m^2)	Number of failed Stage 2 visual inspections	Time for initial visual inspection (minutes)	Time for second visual inspection (minutes)	Number of clearance samples taken by the 4SC analyst	Brushing time by 4SC analyst (minutes)	Number of times clearance tests failed
Site 1/Enclosure 1	17	0	20	10^	2	3	1†
Site 1/Enclosure 2	98	0	65	-	3	5*	0
Site 2/Enclosure 1	21	1	50	90	3	4.5	0
Site 3/Enclosure 1	40	0	23	20^	3	3	1
Site 4/Enclosure 1	15	1	30	15	2	3	0
Site 4/Enclosure 2	15	0	16	-	2	3	0
Site 4/Enclosure 3	15	0	11	-	2	2	0
Site 5/Enclosure 1	74	0	197	-	4	5	0
Site 6/Enclosure 2	347	1	87	1796~	5	20**	4
Site 7/Enclosure 1	43	1	79	262	3	4.5	0
Site 8/Enclosure 1	47	0	124	-	3	3	0

* Analyst used a plastic bag instead of a brush for dust disturbance

** Average across 2 witnessed clearance tests

†Clearance tests initially passed by 4SC analyst but failed after a recount by the 4SC analyst

^ visual inspection conducted after a Stage 3 failure

~ Calculated as 1803 by the 4SC analyst

Table 3 PCM analysis results from each parallel clearance test carried out by the HSE Scientist

Site - Sample number	Sample volume (litres)	Start time	Finish time	Sample duration (minutes)	Asbestos Material Type	Location	Fibre concentration (f/ml)	Number of fibres counted	Number of fields counted
01-009	480	13:05	13:53	48	AIB (small scale)	Site 1 - Enclosure 1	0.016	29.5	202
01-010	480	13:05	13:53	48	AIB (small scale)	Site 1 - Enclosure 1	0.02	36	201
01-011	480	13:05	13:53	48	AIB (small scale)	Site 1 - Enclosure 1	0.015	27	200
01-023	480	14:00	14:48	48	AIB (small scale)	Site 1 - Enclosure 2	<0.01	8	200
01-024	480	14:00	14:48	48	AIB (small scale)	Site 1 - Enclosure 2	<0.01	7.5	200
01-025	480	14:00	14:48	48	AIB (small scale)	Site 1 - Enclosure 2	<0.01	11	200
01-026	480	14:00	14:48	48	AIB (small scale)	Site 1 - Enclosure 2	<0.01	15	200
01-027	480	14:00	14:48	48	AIB (small scale)	Site 1 - Enclosure 2	<0.01	10	200
02-035	504	10:00	10:41	42	AIB contamination	Site 2	<0.01	7	200
02-036	492	10:00	10:42	41	AIB contamination	Site 2	<0.01	12	200
02-037	492	10:00	10:42	41	AIB contamination	Site 2	<0.01	7.5	200
03-043	480	13:01	13:49	48	AIB	Site 3	0.04	73	206
03-044	480	13:01	13:49	48	AIB	Site 3	0.03	63	200
03-045	480	13:01	13:49	48	AIB	Site 3	0.03	55	200
03-046	480	13:02	13:50	48	AIB	Site 3	0.03	51	200
03-049	480	15:31	16:19	48	AIB	Site 3	<0.01	5	200

Site - Sample number	Sample volume (litres)	Start time	Finish time	Sample duration (minutes)	Asbestos Material Type	Location	Fibre concentration (f/ml)	Number of fibres counted	Number of fields counted
03-050	480	15:31	16:19	48	AIB	Site 3	<0.01	8	200
03-051	480	15:31	16:19	48	AIB	Site 3	<0.01	6	200
03-052	480	15:31	16:19	48	AIB	Site 3	<0.01	12	200
04-012	540	11:22	12:16	54	AIB (small scale)	Site 4 - Enclosure 1	<0.009	3	200
04-013	535	11:22	12:16	54	AIB (small scale)	Site 4 - Enclosure 1	<0.009	5	200
04-014	540	11:22	12:16	54	AIB (small scale)	Site 4 - Enclosure 1	<0.009	13	200
04-028	500	13:33	14:23	50	AIB (small scale)	Site 4 - Enclosure 2	<0.010	4	200
04-029	500	13:33	14:23	50	AIB (small scale)	Site 4 - Enclosure 2	<0.010	9	200
04-030	500	13:33	14:23	50	AIB (small scale)	Site 4 - Enclosure 2	<0.010	5	200
04-042	475	07:49	08:37	48	AIB (small scale)	Site 4 - Enclosure 3	<0.01	4.5	200
04-043	475	07:49	08:37	48	AIB (small scale)	Site 4 - Enclosure 3	<0.01	8	200
04-044	475	07:49	08:37	48	AIB (small scale)	Site 4 - Enclosure 3	<0.01	6	200
05-064	504	15:45	16:48	63	AIB (large scale)	Site 5	0.011	22	200
05-065	504	15:45	16:48	63	AIB (large scale)	Site 5	<0.010	18	200
05-066	504	15:45	16:48	63	AIB (large scale)	Site 5	<0.010	11.5	200
05-067	504	15:45	16:48	63	AIB (large scale)	Site 5	<0.010	19	200
05-068	504	15:45	16:48	63	AIB (large scale)	Site 5	<0.010	15.5	200

Site - Sample number	Sample volume (litres)	Start time	Finish time	Sample duration (minutes)	Asbestos Material Type	Location	Fibre concentration (f/ml)	Number of fibres counted	Number of fields counted
06-148	502	14:11	15:16	64	Sprayed coating	Site 6 – enclosure 2 - 1st clearance test	0.03	51.5	200
06-149	506	14:11	15:16	64	Sprayed coating	Site 6 – enclosure 2 - 1st clearance test	0.02	32	200
06-151	499	14:11	15:16	64	Sprayed coating	Site 6 – enclosure 2 - 1st clearance test	0.02	45	200
06-152	512	14:11	15:16	64	Sprayed coating	Site 6 – enclosure 2 - 1st clearance test	0.1	100	102
06-153	510	14:11	15:16	64	Sprayed coating	Site 6 – enclosure 2 - 1st clearance test	0.02	49.5	200
06-156∞	501	10:15	11:18	63	Sprayed coating	Site 6 enclosure 2 - 2nd clearance test	0.03	57	200
06-157∞	501	10:15	11:18	63	Sprayed coating	Site 6 enclosure 2 - 2nd clearance test	0.02	39.5	200
06-158∞	501	10:15	11:18	63	Sprayed coating	Site 6 enclosure 2 - 2nd clearance test	0.03	64	200
06-159∞	495	10:15	11:18	63	Sprayed coating	Site 6 enclosure 2 - 2nd clearance test	0.02	46.5	200
06-160∞	499	10:16	11:18	64	Sprayed coating	Site 6 enclosure 2 - 2nd clearance test	0.03	52.5	200

Site - Sample number	Sample volume (litres)	Start time	Finish time	Sample duration (minutes)	Asbestos Material Type	Location	Fibre concentration (f/ml)	Number of fibres counted	Number of fields counted
06-161∞	499	10:16	11:18	64	Sprayed coating	Site 6 enclosure 2 - 2nd clearance test	0.03	59.5	200
07-075	480	13:55	14:35	40	Insulation contamination	Site 7	<0.010	2	200
07-076	480	13:55	14:35	40	Insulation contamination	Site 7	<0.010	2.5	200
07-077	480	13:55	14:35	40	Insulation contamination	Site 7	<0.010	3	200
07-078	480	13:55	14:35	40	Insulation contamination	Site 7	<0.010	1	200
08-037	492	14:55	15:36	41	Pipe insulation and debris	Site 8	<0.010	10.5	200
08-038	492	14:55	15:36	41	Pipe insulation and debris	Site 8	<0.010	14.5	200
08-039	492	14:55	15:36	41	Pipe insulation and debris	Site 8	<0.010	6.5	200
08-040	492	14:55	15:36	41	Pipe insulation and debris	Site 8	<0.010	5	200
08-041	492	14:55	15:36	41	Pipe insulation and debris	Site 8	<0.010	9.5	200

∞ The clearance air test passed two days later when HSE scientists could not attend. Long duration reassurance air sampling during enclosure dismantling were carried out on the 17/12/18 see results in table 5

Table 4 TEM analysis results from selected parallel clearance tests (HSE scientists)

Site - sample number	Sample duration (minutes)	Sample volume (litres)	PCM fibre concentration (f/ml)	TEM Asbestos fibre concentration (f/ml)	TEM Total asbestos fibres counted	TEM Amosite fibres counted	TEM Chrysotile fibres counted
01-009	48	480	0.016	0.0049	5	4	1
01-010	48	480	0.02	0.0089	9	8	1
01-011	48	480	0.015	0.0049	5	5	0
01-025	48	480	<0.01	0.0069	7	7	0
01-026	48	480	<0.01	0.0049	5	4	1
01-027	48	480	<0.01	0.0059	6	6	0
02-035	42	504	<0.01	<0.0030	0	0	0
02-036	41	492	<0.01	<0.0047	1	0	1
03-043	48	480	0.04	0.0581	45	45	0
03-046	48	480	0.019	0.0327	32	32	0
03-050	48	480	<0.01	0.0050	5	5	0
03-052	48	480	<0.01	0.0040	4	4	0
04-014	54	540	<0.01	<0.0075	3	3	0

Site - sample number	Sample duration (minutes)	Sample volume (litres)	PCM fibre concentration (f/ml)	TEM Asbestos fibre concentration (f/ml)	TEM Total asbestos fibres counted	TEM Amosite fibres counted	TEM Chrysotile fibres counted
04-029	50	500	<0.01	<0.0029	0	0	0
04-043	60	475	<0.01	<0.003	0	0	0
05-068	63	504	<0.01	0.0198	42	41	1
05-066	63	504	<0.01	0.0197	20	20	0
05-064	63	504	0.011	0.0463	47	47	0
05-065	63	504	<0.01	0.0266	27	27	0
05-067	63	504	0.01	0.0355	36	36	0
06-148	64	502	0.03	0.0540	30	30	0
06-158	63	501	0.03	0.0933	30	30	0
07-077	40	480	<0.01	<0.0030	0	0	0
08-038	41	492	<0.01	0.0070	7	7	0

Table 5 PCM results from static monitoring during enclosure dismantling

Site - sample number	Sample volume (litres)	Sample duration (minutes)	Asbestos material type	Reassurance air testing during enclosure dismantling operations	PCM fibre concentration (f/ml)	Number of fibres counted	Number of fields counted
01-013	480	60	AIB (small scale)	Enclosure 1	0.012	23.5	200
01-029	480	60	AIB (small scale)	Enclosure 2	<0.010	9.5	200
01-030	480	60	AIB (small scale)	Enclosure 2	<0.010	8	200
02-038	870	87	AIB contamination	LHS of delivery office in front of scaffold - Day 5	<0.006	10	200
04-019	624	78	AIB (small scale)	Next to Enclosure 1 – Day 2	<0.008	4	200
04-048	474	60	AIB (small scale)	Next to Enclosure 3 – Day 5	<0.010	12.5	200
05-076	757	78	AIB (large scale)	Inside enclosure – Day 6	<0.006	9.5	200
05-077	960	97	AIB (large scale)	Between airlock and NPU – Day 6	<0.005	7	200
06-162	756	42	Sprayed coating	Enclosure 2 - 17.12.18	<0.006	11	200

Site - sample number	Sample volume (litres)	Sample duration (minutes)	Asbestos material type	Reassurance air testing during enclosure dismantling operations	PCM fibre concentration (f/ml)	Number of fibres counted	Number of fields counted
07-079	550	85	Insulation contamination	Next to enclosure by NPU– 03.05.19	<0.009	3	200
07-080	550	54	Insulation contamination	Next to enclosure by baglock– 03.05.19	<0.009	3.5	200
08-049	612	120	Pipe insulation and debris	Enclosure area – 18.10.19	0.015	35.5	200
08-050	744	120	Pipe insulation and debris	Enclosure area - 18.10.19	0.012	34	200

Table 6 PCM results from personal monitoring during enclosure dismantling

Site sample number	Sample volume (litres)	Sample duration (minutes)	Location or Activity	PCM fibre concentration (f/ml)	Number of fibres counted	Number of fields counted
01-012	100	50	Dismantling enclosure 1	<0.048	8	200
01-028	192	64	Dismantling enclosure 2	<0.025	4	200
03-054	180	60	Dismantling enclosure	0.07	45	200
04-020	360	120	Dismantling Enclosure 1	<0.013	9	200
04-034	111	37	Dismantling Enclosure 2	<0.043	6	200
04-049	99	33	Dismantling Enclosure 3	<0.048	7	200
05-070	248	84	Dismantling enclosure	<0.019	10	200
05-071	202	84	Dismantling enclosure	<0.024	7	200
05-072	245	83	Dismantling enclosure	<0.020	4.5	200

Site sample number	Sample volume (litres)	Sample duration (minutes)	Location or Activity	PCM fibre concentration (f/ml)	Number of fibres counted	Number of fields counted
05-073	203	83	Dismantling enclosure	<0.024	6	200
07-081	135	54	Dismantling enclosure	<0.036	2.5	200
07-082	133	54	Dismantling enclosure	<0.036	3	200
07-083	138	55	Dismantling enclosure	<0.035	3.5	200
08-045	129	86	Dismantling enclosure	<0.037	8	200
08-046	132	85	Dismantling enclosure	<0.036	8.5	200
08-047	170	83	Dismantling enclosure	0.03	20	200
08-048	178	89	Dismantling enclosure	0.03	22.5	200

Table 7 PCM results from static monitoring carried out on Site 6 enclosure 1 following a large 4SC that was not witnessed by HSE scientists (enclosure 2 was witnessed)

Site - sample number	Sample volume (litres)	Time on	Time off	Sample duration (minutes)	Location/Activity	PCM fibre concentration (f/ml)	Number of fibres counted	Number of fields counted
06-019	1418	08:25	16:10	465	Reassurance (Enclosure 1) - Ground floor – 15.11.18	<0.003	4	200
06-023	1427	07:36	15:24	468	Reassurance (Enclosure 1) - Ground floor – 16.11.18	<0.003	18	200
06-034	960	07:50	11:53	243	Reassurance (Enclosure 1) - Ground floor – 17.11.18	<0.005	0.5	200
06-041	2444	07:46	17:57	611	Reassurance (Enclosure 1) - Ground floor – 19.11.18	<0.002	4	200
06-047	976	11:56	13:45	109	Reassurance (Enclosure 1) - Ground floor – 19.11.18	<0.005	0	200
06-059	2364	07:40	17:31	591	Reassurance (Enclosure 1) - Ground floor – 20.11.18	<0.002	17	200
06-072	2435	07:47	17:39	594	Reassurance (Enclosure 1) - Ground floor – 21.11.18	Sample occluded uncountable	N/A	N/A
06-081	1936	07:45	15:55	490	Reassurance (Enclosure 1) - Ground floor – 22.11.18	<0.002	15.5	200
06-102	1544	8.59	16:08	429	Reassurance (Enclosure 1) - Ground floor – 23.11.18	<0.003	7.5	200

Site - sample number	Sample volume (litres)	Time on	Time off	Sample duration (minutes)	Location/Activity	PCM fibre concentration (f/ml)	Number of fibres counted	Number of fields counted
06-117	2124	07:38	16:29	531	Reassurance (Enclosure 1) - Ground floor – 26.11.18	<0.002	9	200
06-126	1308	08:42	14:09	327	Reassurance (Enclosure 1) - Ground floor – 27.11.18	0.005	24	200
06-135	1700	08:25	15:30	425	Reassurance (Enclosure 1) - Ground floor – 28.11.18	0.003	20.5	202
06-147	932	07:26	11:19	233	Reassurance (Enclosure 1) - Ground floor – 29.11.18	<0.005	12	200

Table 8 TEM results from selected static monitoring samples taken during enclosure dismantling

Site sample Number	Sample duration (minutes)	Sample volume (litres)	PCM fibre concentration (f/ml)	TEM fibre concentration (f/ml)	TEM Number of amosite fibres counted	TEM Number of chrysotile fibres counted	TEM Number of tremolite fibres counted
01-012	50	100	<0.048	0.0050	5	0	0
03-054	60	192	0.07	0.0220	22	0	0
04-020	120	360	<0.013	<0.0046	1	0	0
04-049	33	99	<0.048	<0.0112	3	0	0
05-070	84	248	<0.019	0.0080	7	0	1
07-083	55	138	<0.035	<0.005	0	0	0
08-048	89	178	0.03	0.0090	8	1	0

Table 9 TEM analysis of selected personal monitoring samples taken during enclosure dismantling

Site - sample number	Sample duration (minutes)	Sample volume (litres)	PCM fibre concentration (f/ml)	TEM fibre concentration (f/ml)	TEM Number of amosite fibres counted	TEM Number of chrysotile fibres counted
01-013	60	480	0.012	<0.0078	3	0
04-048	60	474	0.007	0.0048	5	0
05-076	78	757	0.003	0.0079	8	0
06-163	42	756	0.004	<0.0048	1	0
07-080	57	550	0	<0.0030	0	0
08-049	120	612	0.015	<0.0078	3	0

Table 10 TEM analysis of selected static monitoring samples taken after the 4SC of enclosure 1 at Site 6

Site sample number	Date	Sample duration (minutes)	Sample volume (litres)	PCM fibre concentration (f/ml)	TEM fibre concentration (f/ml)	TEM Number of amosite fibres counted
06-041	19.11.18	611	2444	0.002	<0.0030	0
06-059	20.11.18	591	2364	0.002	<0.0029	0
06-081	22.11.18	490	1936	0.001	0.0058	6
06-117	26.11.18	531	2124	0.003	<0.0075	3
06-126	27.11.18	327	1308	0.004	0.0039	4
06-135	28.11.18	1275	1700	0.003	<0.0030	0

Table 11 PCM analysis of personal monitoring samples taken from analysts during visual inspections

Site sample number	Sample volume (litres)	Sample duration (minutes)	Location or Activity	PCM fibre concentration (f/ml)	Number of fibres counted	Number of fields counted
01-022	130	65	Analyst visual inspection of enclosure 2 (AIB)	<0.036	4	200
02-034	150	50	Visual inspection of enclosure (AIB)	<0.032	6	200
03-047	69	23	Visual inspection of enclosure (AIB)	0.13	36	200
04-027	90	30	Analyst visual Enclosure 2 (visual failed) AIB	<0.053	2	200
04-032	64	16	Analyst visual Enclosure 2 (AIB)	<0.075	1	200

Site sample number	Sample volume (litres)	Sample duration (minutes)	Location or Activity	PCM fibre concentration (f/ml)	Number of fibres counted	Number of fields counted
04-047	39	11	Analyst visual Enclosure 3 (AIB)	<0.123	0.5	200
05-063	443	197	Analyst visual Inspection (AIB)	<0.011	11.5	200
06-127	131	87	Analyst visual Enclosure 2 (Spray coating)	0.05	25.5	200
06-154	150	38	Brush disturbance (Spray coating)	0.03	19	200
06-155	N/A	N/A	Brush disturbance (Spray coating)	Pump failed; filter clear	N/A	N/A
07-070	63	79	4SC visual (Thermal Insulation)	<0.076	0	200
07-071	262	262	4SC visual (Thermal Insulation)	<0.018	4	200
08-044	248	124	4SC analyst visual (thermal insulation)	<0.019	14.5	200

Table 12 TEM analysis of selected personal monitoring samples taken from analysts during visual inspections

Site sample number	Sample description	Sample duration (minutes)	Sample volume (litres)	PCM fibre concentration (f/ml)	TEM asbestos fibre concentration (f/ml)	Number of fibres counted	Number of amosite fibres counted	Number of chrysotile fibres counted
01-022	Visual inspection of Enclosure 2	65	130	<0.036	0.0090	9	8	1
03-047	Visual inspection	23	69	0.13	0.0309	12	12	0
04-032	Visual inspection of Enclosure 2	16	64	<0.075	<0.0069	0	0	0
05-063	Visual Inspection	197	443	<0.011	0.0070	7	6	1
06-108	Visual Inspection	179	170	<0.028	0.0586	30	30	0
06-127	Visual Inspection	87	131	0.05	0.0569	30	30	0
06-154	Visual Inspection	38	524	0.032	0.0441	30	30	0
07-070	Visual Inspection	79	63	<0.076	<0.003	0	0	0

Site sample number	Sample description	Sample duration (minutes)	Sample volume (litres)	PCM fibre concentration (f/ml)	TEM asbestos fibre concentration (f/ml)	Number of fibres counted	Number of amosite fibres counted	Number of chrysotile fibres counted
08-044	Visual Inspection	124	248	<0.019	0.0110	11	11	0

4 Discussion

4.1 Introduction

In this section, the project results are reviewed and interpreted to understand how they inform our knowledge of the 4SC process following licensed asbestos removal work. Where relevant, the site observations of HSE scientists are included to add context to the results. These results and observations were used to assess the exposure risk during the 4SC process for analysts and to assess whether the 4SC process was being conducted in-line with guidance. These results were also compared to past work by HSE and other similar studies.

4.2 Observed work practices and 4SC procedure

All four stages of the 4SC procedure were observed by HSE scientists in seven of the eight sites. Site 6 had incomplete observations for the full 4SC process and details on this clearance process are discussed in Section 4.4. HSE scientists kept interventions with the 4SC analyst to a minimum during the observed work, to minimise potential interference of the 4SC process.

4.2.1 Supervisor visual inspection and handover to 4SC analyst

Before an enclosure is handed over to the 4SC analyst to start the 4SC process, the LARC site supervisor is required to make a visual assessment of their own to determine that the enclosure is ready for the 4SC analyst (HSG247, HSE 2006). The LARC's visual inspection should be to the same standard as the 4SC analyst's visual inspection. It should not pass if there is any visible dust or debris remaining on the surfaces in the enclosure. If visible dust or debris is present during the visual inspection of the 4SC (Stage 2), the LARC representative may remain inside the enclosure to conduct any additional cleaning required. However, under HSG 248 (HSE 2021) the 4SC analyst should fail the inspection, leave the enclosure and formally issue a failed CfR if cleaning is likely to take longer than 10-minutes. If any cleaning is required, the 4SC analyst should leave the enclosure.

HSE scientists observed supervisors performing visual inspections on each site. The 4SC analyst was informed each time the supervisor passed each inspection. This was formally recorded on a 'site handover form' for sites five to eight. The use of this form was a proposed outcome from HSE's analyst inspection program (HSE 2018), because HSE had observed that Supervisors were not always conducting visual inspections.

On all eight sites, further cleaning was necessary following the supervisors visual. At two sites, the supervisor exited the enclosure and stated significant cleaning was required before the area could be handed over to the 4SC analyst.

Several enclosures failed on the first 4SC analyst visual, suggesting either the LARC Supervisor missed dust and debris during their inspection, or that their standard of acceptable conditions was different from the 4SC analyst. It has been identified that HSG247 training requirements (Chapter 4) did not cover any training for the supervisor to conduct a visual inspection to the standards identified in HSG248. The trade organisations and training bodies accepted this and are progressing with training requirements for the Supervisors visual inspection. Other factors such as explaining responsibilities and the handover form may have contributed to an improvement of supervisor visual inspections but this research indicates that they may not yet be as exacting as those carried out by 4SC analysts.

4.2.2 Observations from Stage 1 of the 4SC procedure

Stage 1 is an initial check of site conditions which includes the following activities among others:

- checking the plan of work to understand the scope of the removal work.
- checking that the risk assessment is still suitable and sufficient and there are no additional hazards.
- checking inside the enclosure using the viewing panels and CCTV to ensure there is no obvious debris or equipment left inside the enclosure.
- checking transit and waste routes for debris.
- checking the DCU to ensure it is functional and clean.
- checking that there is suitable and sufficient access equipment and lighting for inspection activities.

If an enclosure fails at Stage 1 of the 4SC procedure it can suggest significant failings with the removal work process. Reasons for failure could include lack of proper paperwork eg, no plan of work, a significant amount of debris still in the enclosure and visible through the viewing panel, debris on the waste route or obvious holes/tears in the enclosure.

No major concerns were raised by HSE scientists in relation to the 4SC analysts witnessed work during Stage 1 of the eight site visits. No enclosures failed at Stage 1 on any of the site visits. The removal work on all sites had been witnessed by HSE scientists, therefore the likelihood of significant issues being present was relatively low.

4.2.3 Observations from Stage 2 of the 4SC procedure

Duration of visual inspections

Table 2 details the duration of each visual inspection. Each individual visual inspection will vary depending on the individual site/enclosure circumstances. For example, the degree of ‘sheeting out’ by the licensed contractor will greatly affect the time needed to conduct a visual inspection and ceiling voids may be devoid of fixtures/fittings or full of them; this will also affect the time required to do the inspection.

HSE scientists did not observe anything to suggest that the length of time taken by the 4SC analyst performing visual inspections was unsuitable. However, results from Site 3 showed the 4SC analyst passed the first visual inspection after 23 minutes, the subsequent 4SC air test failed. The personal monitoring sample taken from the 4SC analyst indicated a high airborne fibre concentration (See section 4.5.1). This suggests areas where dust and debris were present, this may have been missed and would have benefited from a longer visual inspection. This is supported by the subsequent re-inspection of the area by both the 4SC analyst and the LARC supervisor where an area was identified that required additional cleaning.

Cleaning during visual inspections

CAR 2012 (Regulation 8) requires employers to obtain a licence from HSE before they can carry out any licensable work with asbestos. Therefore, 4SC analysts should not carry out cleaning during visual inspections, as this could be considered as an asbestos removal work activity. Previous inspections during the analyst inspection programme (HSE 2018) noted 4SC analysts cleaning areas of dust and debris during visual inspections.

HSE scientists did not observe 4SC analysts cleaning within the enclosure during any of the eight site visits. It demonstrated that during witnessed visual inspections (as part of this project), 4SC analysts understood they should not clean any dust or debris. However, anecdotal evidence obtained by HSE scientists from 4SC analysts on site, suggested that they had previously undertaken cleaning activities. All 4SC analysts stated they now only identified areas for cleaning to be completed by the removal workers.

Although the 4SC analysts were not witnessed directly carrying out cleaning at this stage, cleaning did take place during the visual inspection stage. On all sites at least one removal worker, and on occasion two or more, accompanied the 4SC analyst into the enclosure for the visual inspection (see Figure 3). This was to perform any minor cleaning required, as directed by the 4SC analyst. This practice is following guidance, however, due to the number of removal workers required, it would suggest that the enclosure was not clean enough. On some sites 4SC analysts remained in the enclosure whilst this minor cleaning was being conducted. This is not seen as good practice.

Figure 3 Analyst and trainees (white coveralls) carrying out visual inspection accompanied by removal workers

In four of the enclosures, the visual inspection duration was longer than one hour. Removal workers were also witnessed cleaning for most of the visual inspection time. This suggested that a full and proper final clean was not undertaken. The updated HSG 248 now requires a 10-minute limit on cleaning during visual inspection. Under these new criteria, all four visual inspections would have failed. It is understood that the removal workers may have just been ‘keeping busy’ whilst the inspection was being conducted but, in most cases, they were being directed by the 4SC analyst to clean areas. Section 4.5.2 covers 4SC analysts RPE usage choice and whether it was suitable for the length of time of visual inspections.

A requirement of the visual inspection by 4SC analysts is to check any equipment left inside the enclosure such as mobile scaffold platforms or ladders, for the presence of dust or debris. On three occasions 4SC analysts did not inspect mobile scaffold platforms and failed to notice missing caps from the tops of the scaffold poles. Scaffold poles without caps have the potential for collecting fallen debris during removal work. In three cases HSE scientists pointed this out to the 4SC analyst following the visual inspection and the LARC was informed by HSE scientists. If a 4SC analyst identifies this during a visual inspection, they should inform the LARC to action this and if the interior of the scaffold poles are deemed uncleanable, they should be identified as requiring disposal of as asbestos waste at the end of the works. This was observed on Site 7 where the 4SC analyst detailed in the CfR at Stage 4 that the scaffold poles that had been left open during removal, were bagged as waste and disposed of accordingly. This decision was made by the 4SC analyst and removal contractor.

4.2.4 Observations from Stage 3 of the 4SC procedure

Disturbance air testing carried out in Stage 3 is a vital part of the 4SC procedure. It provides a measure of the potential peak airborne fibre levels when the area is reoccupied. However, it is important to note that it should only be considered effective in combination with a thorough visual inspection having preceded it (in Stage 2) and as part of the 4SC.

For the air monitoring result to be an estimate of the fibre concentration at a potential peak level, fibres and dust on surfaces must be disturbed. This is achieved by brushing surfaces inside the enclosure (both HSG 248, HSE 2005 & 2021). The guidance also states that the brushing time must be a minimum of 1.5 minutes per sampling point with the number of sampling points determined by the size and complexity of the enclosure. This brush disturbance replicates the scenario of the area being brushed / swept to ensure that any dust / fibres are airborne whilst the air is sampled. The air test results provide an estimate of the potential risk from fibres left after removal that post-4SC activities may disturb. It would be expected that unless a disturbance activity equivalent to, or greater than the brushing activity conducted during the disturbance test was carried out that fibre concentrations would be reduced. Once Stage 3 passes, the enclosure will be removed introducing a dilution factor to any airborne fibres that would be likely to be disturbed by future activities in the area.

Table 2 shows the time 4SC analysts spent brushing during the witnessed 4SCs on each site. In four out of eleven enclosures brushing was not carried out for the minimum time set out in guidance. The guidance in HSG248 also states that all surfaces around the sampling point need to be brushed which can lead to times greater than the minimum. During the 4SC for Site 1, in the second enclosure the 4SC analyst did not use a brush to disturb surfaces instead using a plastic bag. When questioned, this was due to the 4SC analyst having run out of brushes and they had not renewed their stock prior to the 4SC. A plastic bag is very unlikely to disturb dust and fibres from surfaces in the same way a brush would and a brush is named as the instrument to use for the dust disturbance within the ACOP L143 (HSE 2013a).

Parallel clearance air tests are discussed in Section 4.3.1.

4.2.5 Observations from Stage 4 of the 4SC procedure

The main observations from Stage 4, centre around enclosure re-use. None of the observed CfRs noted that any of the airlocks, baglocks or enclosure sheeting were re-used. The re-use of enclosure polythene from any part of the set-up is contrary to HSE guidance (HSE 2006) and should be brought to the attention of the dutyholder either through communication or via records. The 4SC analysts when inspecting the area at Stage 4 did not always wear PPE including RPE. Considering that some of the reassurance testing results at this stage were above the clearance indicator, the risk assessment and controls for the analysts should take this into account. As most of the sites had ongoing work after the HSE Scientists had concluded their observations it was not possible to check that all equipment had been removed as it was being used again in other enclosures. Where multiple activities, for example demolition work, generating dust or multiple live enclosures were taking place concurrently, Stage 4 can become more complex. Therefore, supporting notes may be necessary to explain, for instance, the shared transit and waste routes. The wheels of NPUs and mobile scaffold towers, when located within the enclosure, was identified as an area where there needed to be a thorough inspection by the 4SC analyst. Scaffolding either in tower form or as a standalone structure also needs to be covered in the records and there was evidence of this in CfRs examined. If scaffolding used as part of the structure of the enclosure is remaining in-situ post Stage 4, then the area must be inspected for any residual enclosure materials, dust build-up or ACMs as part of the Stage 4 inspection. The associated risks and potential for debris when dismantling should be made clear by the analyst to the duty holder so that suitable precautions can be taken.

4.2.6 Observations on failure rate of 4SC procedure

Table 2 shows that in 6 of the 11 enclosures witnessed across the eight sites, the 4SC analysts failed at least one stage (54.5% failure rate). In 2013/14 HSE sent a questionnaire to all UKAS accredited 4SC analytical companies asking how often their 4SC analysts failed enclosures (HSE 2018). The questionnaire was sent to 140 ISO/IEC17025 (UKAS) accredited laboratories with 70% of organisations responding. The data showed that between 1 and 20% of their 4SCs failed, with 10% of companies saying it was less than 1%. This is significantly different to the rate witnessed by HSE scientists on the eight sites visited as part of this project.

There are several reasons why an observed 4SC could fail compared to an unobserved one:

- a 4SC analyst may spend more time on the visual inspection as they want to make sure they are witnessed conducting a thorough inspection.
- small amounts of dust left at Stage 2 would normally be ‘masked’ by dust generated by the brushing activity at Stage 3.
- having an independent party on-site as a witness may make a 4SC analyst feel more confident in being able to issue a failed CfR knowing that the LARC is less likely to raise an objection or have a confrontation during the assessment.
- when unobserved they may also take the approach of not issuing a formal failure but advising the LARC of what needs to be corrected and waiting until that has happened before continuing with the 4SC, including allowing significant cleaning to happen during the visual.
- on longer visual inspections interpreting what 10-minutes cleaning is when there is a minute here or a minute there becomes a subjective activity.
- a 4SC analyst could fail an area for very minor amounts of dust or debris that could be cleaned without a failure to show the observers that they were doing a thorough job.

Anecdotally from speaking to the 4SC analyst and the LARC supervisor, the last bullet point may have been the case for failed visuals on Site 2 and Site 4. However, HSE scientists did not carry out a thorough visual themselves so cannot make this judgement with certainty. HSE scientists also spoke to 4SC analysts generally about their work during the project. One aspect the majority of 4SC analysts spoken to commented on was that time pressure from either, their company to get work done and move on to the next job or from the LARC on site, did on occasion affect their work and their decisions. Time pressures either actual or perceived can significantly impact on the impartiality and effectiveness of the 4SC process and this is potentially an area for further investigation.

4.3 Parallel clearance results

4.3.1 PCM analysis results and observed differences between HSE and 4SC analyst counts

HSE scientists ran their own static samples alongside the 4SC analyst's clearance samples. HSE scientists generally ran one more sample than the 4SC analyst to gather more data and mitigate against any pump failures invalidating the results. Pumps were collected from the enclosure and final flow rates measured by HSE scientists.

Although only the 4SC analyst's samples formed part of the accredited sampling for the formal 4SC procedure, all LARC site supervisors considered the 4SC to have passed only if both the 4SC analyst and the HSE scientist obtained results below 0.01 f/ml. There was only one occasion where there was a difference between the 4SC analyst's and HSE scientists' assessment of whether the fibre concentration was above or below 0.01 f/ml, this was for enclosure 1 on Site 1. The 4SC analyst reported that the tests had passed with results less than 0.01 f/ml (fibre counts ranged from 7-13 fibres), whereas the HSE scientists' results ranged from 0.15 f/ml to 0.2 f/ml (27 to 36 fibres in 200 fields). The 4SC analysts' slides were recounted and the area was failed by the 4SC analyst on this occasion. On all other occasions, HSE scientists and 4SC analysts agreed on whether 4SC air tests had passed or failed.

Previously, HSE scientists visited licensed removal sites with the aim of assessing the standard of clearance tests at the time and further developing guidance relating to clearances. As part of this work parallel clearance samples were taken on eleven of the sites visited and for twelve enclosures in total (Burdett 2005). For this work, HSE scientists counted the samples after the site visit when they returned to the laboratory. The results from the parallel clearance samples indicated eight out of twelve of the enclosures should have passed whereas eleven out of twelve were passed by the on-site 4SC analyst. This means there was disagreement between HSE and the on-site 4SC analyst as to whether an enclosure should have passed on three out of twelve occasions. The research also suggested that there was an even greater difference in individual results with only 52% of HSE results below 0.01 f/ml and an estimated 95% below 0.01 f/ml for the samples taken and analysed by the on-site 4SC analysts. However, the on-site 4SC analyst results were not formally recorded for comparison.

In this project, there were multiple Stage 3 failures and the results independently counted by the 4SC analysts and HSE scientists were within statistical agreement. There was only the one set of results, described above, where the 4SC analyst and the HSE scientist results were not in agreement and this was discussed between the LARC supervisor, HSE and analyst. The analyst decided to recount the filter which resulted in an airborne fibre concentration above the clearance indicator. The area was re-cleaned, re-inspected and passed a subsequent air test.

This shows an improvement in correlation of the Stage 3 results compared to the 2005 study (Burdett 2005). In 2005 the HSE Scientists fibre counts were <0.01 f/ml in 17 of 33 cases whilst the onsite analyst recorded <0.01 f/ml in 31 of 33 cases. In the 2005 research, the 4SC analyst would have known that the HSE counts were taking place after the site work had been complete and the area had formally passed the 4SC. In the most recent research the HSE scientists conducted fibre counting on-site and the 4SC analysts were aware this was happening. The 4SC analysts were therefore aware that any discrepancy between the two results could be called into question.

4.3.2 Results from TEM analysis of parallel clearance samples

Twenty-four parallel clearance samples were analysed by TEM (45% of the total taken). To achieve the sensitivity required by this research a sample could take up to a working day to prepare and analyse. The results are shown in Table 4 in Section 3 of this report. The aim of the analysis was to assess in more detail the asbestos fibre concentration present during clearance testing. One or two samples were selected for TEM analysis from each set of parallel clearance samples taken for a given enclosure. For Site 1 and Site 5, the full set of parallel clearance samples taken were analysed by TEM. For Site 1, this was to provide more information about on-site differences between HSE scientists and the 4SC analyst's counts and Site 5 was chosen after the initial TEM analysis on two samples showed a large difference between the original PCM fibre concentration and the TEM asbestos fibre concentration. There is not a direct comparison between PCM and TEM as PCM records all countable fibres observed whereas TEM only records asbestos fibres so PCM should, theoretically, give higher results. The sample pool is quite small and consequently, no firm conclusions can be drawn but it should be borne in mind that TEM is more accurate at the low sensitivity end of the fibre diameter spectrum particularly those fibres around 0.2µm diameter. It is not known whether asbestos removal processes, including cleaning or mechanical activities are likely to generate airborne fibres with diameters around 0.2µm diameter.

Twenty-four samples from parallel clearances were analysed by both PCM and TEM for comparison as shown in Table 4. There were 9 samples where the TEM fibre concentration was higher than the PCM fibre concentration. Two of these were on Site 3, five on Site 5 (discussed separately in 4.3.3 below) and two on Site 6. The 9 samples had a total of 309 fibres (defined as countable if they were >5µm long; <3µm wide and with an aspect ratio greater than 3:1) counted by TEM of which there was only 1 chrysotile fibre the rest being amosite. All of Site 3 and Site 6 samples where the TEM fibre concentration was higher, were above the limit of detection for both PCM and TEM methods. There were a significant portion of fibres counted by TEM with diameters between 0.2 – 0.4µm and length <15µm (Figure 4) which would be more difficult to see with PCM, particularly if the fibres had penetrated the filter, end on (Figure 5), so that the fibre diameter was prominent rather than its length. The filter preparation method with TEM analysis allows all of these fibres to be seen and counted which is not necessarily the case with PCM and some SEM fibre counting methodologies. This is potentially an area for further research with a much larger pool of samples needed for it to be statistically viable. Both sample preparation and analytical method would need to be carefully considered.

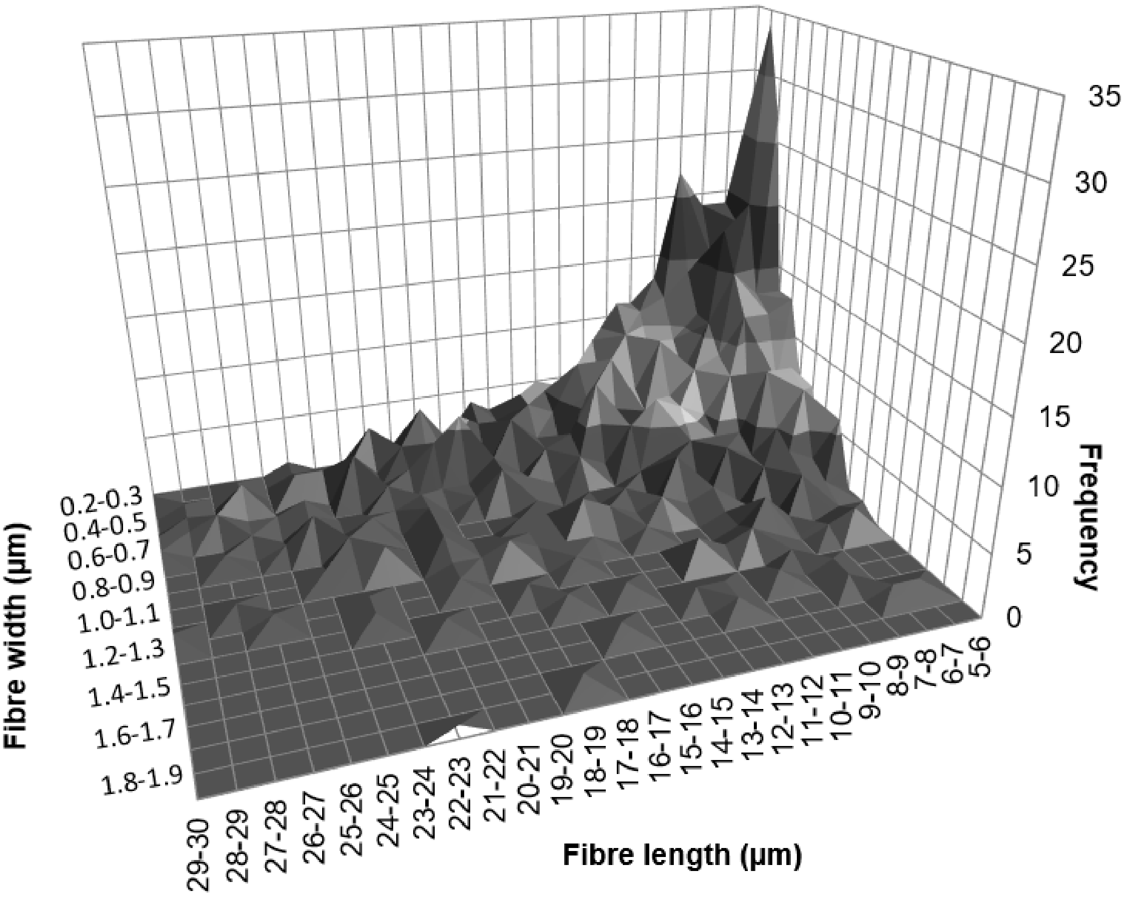


Figure 4: Size distribution of asbestos fibres from all sites analysed by TEM that were within the WHO fibre counting rules (>5µm long, <3µm wide and with an aspect ratio greater than 3:1)

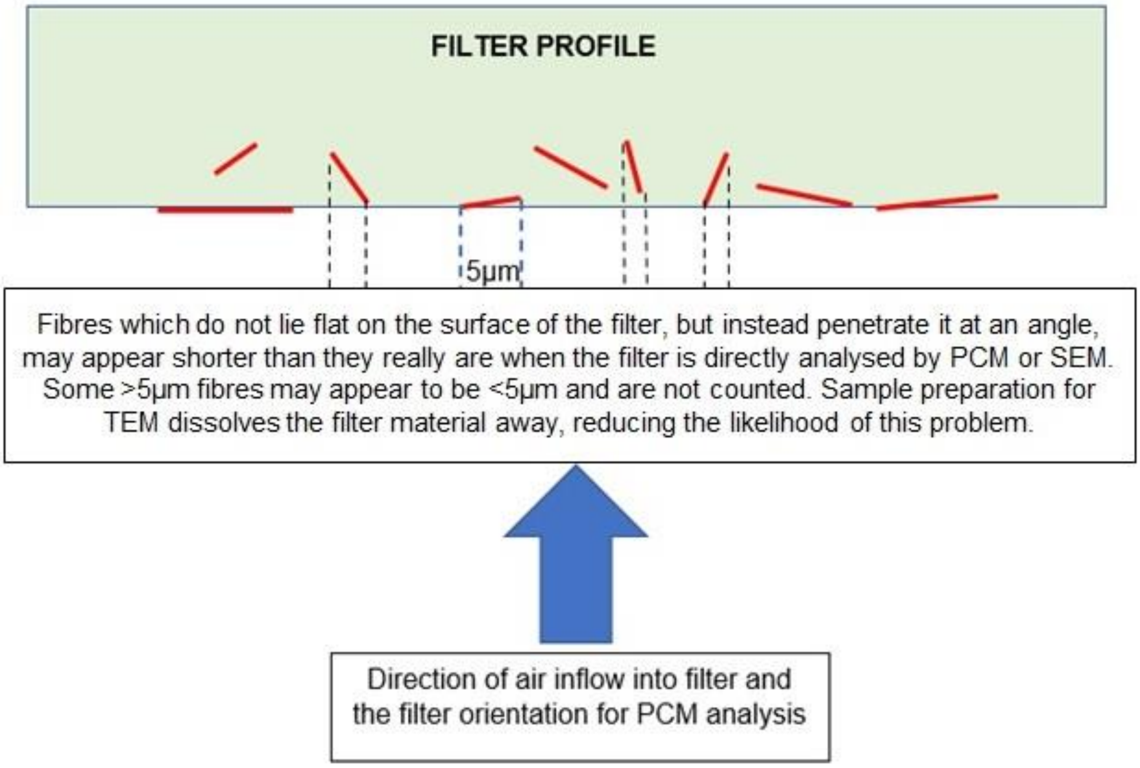


Figure 5: Schematic showing fibre penetration of the filter that may prevent fibres being counted by PCM and some SEM filter preparation methods. The black dotted lines signify fibres >5µm that would not be counted under WHO fibre counting rules due to their fixed orientation within the filter making them seem <5µm long

4.3.3 TEM analysis of parallel clearance tests taken on Site 5

Initially, only sample 05-068 was selected for TEM analysis after the site visit was completed. The TEM result for this sample gave an asbestos fibre concentration that was over twice that of the PCM fibre concentration recorded from analysis on-site and above the 0.01 f/ml clearance indicator. Therefore, it was decided to analyse all parallel clearance samples from Site 5 by TEM to determine whether this difference occurred for all samples.

When analysed by TEM, the five samples initially analysed using PCM by HSE scientists on-site, did show a consistent difference between the on-site PCM fibre concentration and the TEM asbestos fibre concentration with the TEM asbestos fibre concentration being between two and four times higher. To see whether there was an issue with the original PCM on-site analysis by the HSE scientist, the slides were reanalysed, once by the original HSE scientist who had carried out the analysis and once by a different HSE scientist who had not previously seen the slides. The results, along with the TEM analysis results, can be seen in Figure 6. The reanalysis results were not significantly different from the original on-site analysis results and in all cases were within the 95% confidence limits of the original HSE analysis (PCM confidence limits shown as error bars in Figure 6).

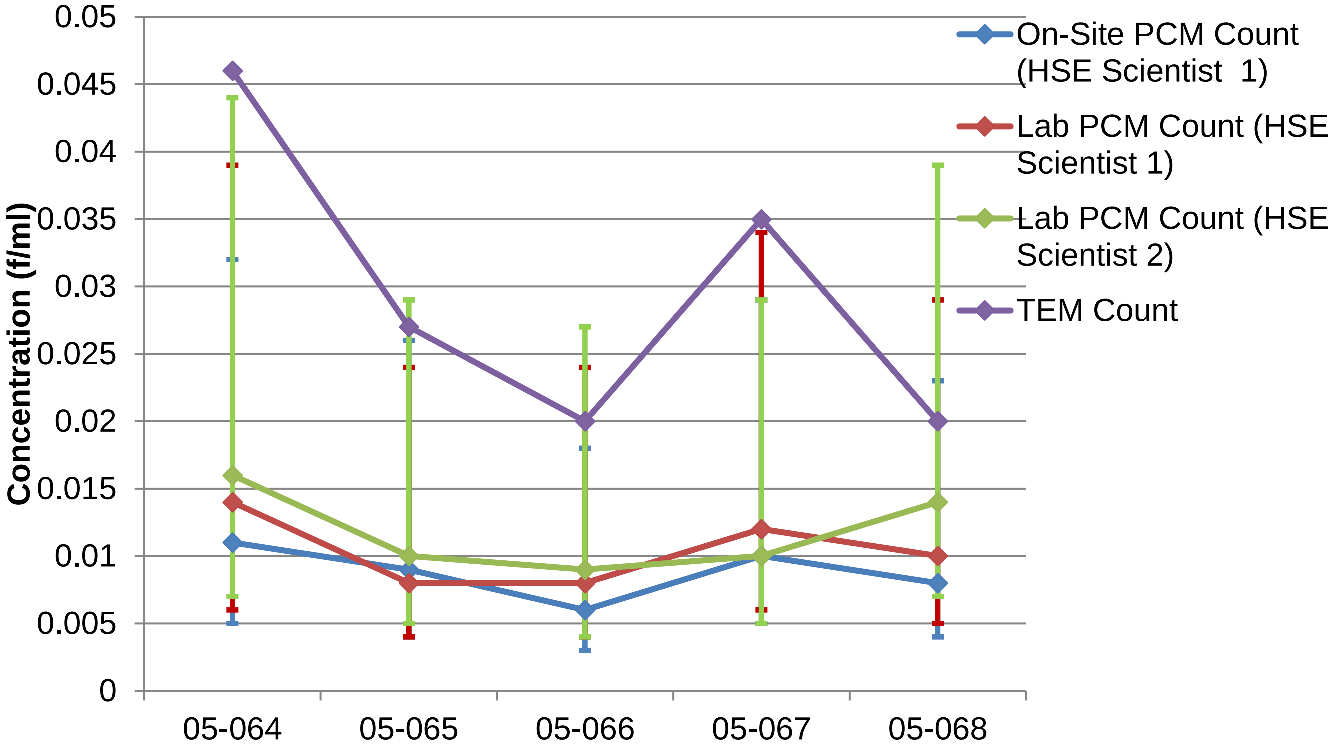


Figure 6 Graph showing the fibre concentrations for parallel clearance samples taken on Site 5

Given that the TEM analysis only included PCM equivalent fibre sizes (and only asbestos fibres) it is not clear why there would be such a large discrepancy between the results although there were a significant portion of fibres with diameters between 0.2 – 0.4µm and length <15µm. There was no obvious unevenness in the deposit when checked at low magnification as part of the PCM analysis and the relative consistency between repeated PCM analysis results make cross filter variation unlikely. It is not possible to be sure from this relatively small set of samples whether these results represent an anomaly or is something that will occasionally be seen when comparing TEM and PCM analysis of airborne fibres.

4.3.4 Limitations of the analysis carried out

It was not an original aim of the project to carry out a formal assessment of the potential difference between PCM and TEM analysis for measuring asbestos fibres in air. Samples were only selected for TEM analysis to give an indication of the asbestos fibre concentration during clearance testing on that site.

When looking at the number of results where the TEM asbestos fibre concentration was higher than the upper 95% confidence limit of the PCM fibre concentration it is important to note that a decision was made to focus analysis on sites where significant difference was observed in the initial analysis of samples. This could infer a bias to these results that may not be apparent if all samples had been examined by TEM.

To properly understand the extent of these differences, further work would be needed to consider what number of sample analyses would give a statistically significant answer and then carry out that analysis.

4.4 Witnessed 4SC procedure on Site 6

On Site 6, amosite sprayed coating was removed from 80 linear metres of steel beams. As well as being a friable material with a high asbestos content that can easily leave behind fine settled layers of fibres, ‘overspray’ from the original application, may lead to it being present in areas next to beams and within pitted holes of porous concrete ceilings. As a result, sprayed coating can sometimes be a difficult material to remove fully. This leads to extra challenges during visual inspections after removal and 4SC analysts should take extra care when examining surfaces and should check for overspray in areas adjacent to where the sprayed coating was applied.

The first visual inspection of the witnessed 4SC on Site 6 failed as the 4SC analyst found overspray on areas of the concrete ceiling next to the steel beams. After this failure, removal workers returned to the enclosure to clean the areas where overspray had been found. Following this, the 4SC analyst started a new visual inspection. This inspection lasted roughly six and a half days and was recorded by the 4SC analyst as having taken 1803 minutes a close correlation to the 1796 minutes being recorded by the HSE scientists. For very large enclosures that take several days to visually inspect, a strategy for agreeing how the enclosure is inspected and consequently when an enclosure will fail the visual inspection may be sensible. Any such agreements should include the dutyholder and should be recorded / referenced in the CfR.

Although inspecting areas where sprayed coating has been removed can, as noted, be challenging, this is an unexpectedly long time, approximately seven times longer than the next longest visual inspection witnessed during this project. While the enclosure was larger than those on other sites (see Table 2), the area from which the ACM was removed (80 meters of steel beam) was not significantly larger than other sites.

The 4SC analyst told HSE scientists that originally two 4SC analysts had been assigned to carry out the 4SC, but extra work had come in and the second 4SC analyst was no longer available.

After this extended visual inspection, the brush disturbance air test was carried out. A thorough approach was taken to brushing with long handled brushes used to brush all surfaces with a focus on the surfaces where the ACM had been present, including the concrete ceiling next to beams. The brushing was carried out for 25 minutes which is just over three times longer than the minimum set out in HSG248 for five clearance samples (7.5 minutes), but this was to ensure all surfaces were adequately brushed as stated in guidance.

The first set of clearance air tests failed by quite a large margin, with the results being between 0.02 f/ml and 0.1 f/ml. This suggests that the brushing disturbed a significant number of fibres from surfaces after the visual inspection. This is despite the 4SC analyst having carried out a very lengthy visual inspection.

There then followed a repeated process of removal contractors going back into the enclosure, carrying out further cleaning to surfaces, a further visual inspection passing, and then a brushed disturbance air test giving results above 0.01 f/ml. Finally, the fifth set of clearance air tests passed. For later disturbance air tests, three 4SC analysts carried out the brushing to reduce the overall time brushing took place while still ensuring all surfaces were brushed properly.

As mentioned previously, sprayed coating is very friable with a high percentage asbestos content, typically 55-85% (HSE 2012). It would have been applied at high pressure by handheld hoses, which led to overspray and potentially a high degree of penetration of the porous substrate. This highlights the importance of the brushing activity at Stage 3 to ensure that any hidden pockets of asbestos fibres are disturbed. If a more cursory approach had been taken to the brushing, the clearance air tests may have passed leaving a residual risk to future occupiers from trapped fibres. The minimum brushing time was exceeded on this site to ensure that all surfaces that could harbour fibres were disturbed. This practice was shown to be particularly important when working with materials like spray coating, especially when other sites did not even achieve the minimum disturbance times. It is suggested that if the LARCs use a brush attachment when vacuuming areas where overspray is present on porous substrates this may assist the cleaning process.

In previous work carried out by HSE scientists, the clearance comparison tests included a second set of dust disturbance measurements following on from the air tests initially conducted by the on-site contracted 4SC analyst. At the time, the guidance published in MDHS 39/4 (HSE 1995, superseded by HSG 248 2005) gave no standard method for dust disturbance and only specified that some should take place, although some examples were given, such as banging surfaces, for a minimum of five minutes prior to each hour of sampling. Therefore, disturbance activities at the time were often cursory and not particularly vigorous. The comparison sampling undertaken by HSE, involved five minutes of vigorous brushing by HSE scientists following the completion of the on-site 4SC analyst's sampling, showed significant differences. When HSE scientists carried out their brushed disturbance air testing, fourteen of the fifteen enclosures failed with 80% of results across all enclosures being above 0.01 f/ml. This compared to the 4SC analyst failing only one enclosure. Consequently, guidance introduced in 2005 via HSG 248 (HSE 2005) set out that the method of disturbance should be brushing and gives a minimum time for that brushing based on sample numbers and linked to the size of enclosure.

Given the observed failures on Site 6 and the impact effective brushing can have on clearance results, it would be expected that failures should be observed at Stage 3 of the 4SC procedure on a relatively frequent basis for spray coatings. Whilst spray coating jobs are infrequent, a repeat of the analyst inspection programme questionnaire could be useful in gaining an insight about whether this is happening.

4.5 Analyst exposure

4.5.1 Personal air monitoring results

Thirteen personal monitoring samples were taken from 4SC analysts during visual inspection across the eight site visits. At least one sample was taken on each site.

Looking at the results from all samples, fibre concentrations during visual inspections were below 0.1 f/ml on all but one occasion (see Table 11 sample 3-047) and were always below 0.1 f/ml when a four-hour TWA was calculated. When considering the Assigned Protection Factor (APF) of RPE none of the measured exposures were within a factor of 10 of the control limit of 0.1 f/ml.

The highest result was measured on Site 3, where a fibre concentration of 0.13 f/ml was recorded for a 69-litre sample taken from a 23-minute visual inspection. As previously noted in section 4.2.3 of this report this visual inspection passed but the clearance air tests failed. This result therefore is an indication of the fibre levels that are possible when enclosures are not properly cleaned, and potentially, when a 4SC analyst does not properly inspect surfaces or disturb dust and fibres during brushing. The TEM analysis for this sample showed a much lower asbestos fibre concentration (0.031 f/ml) so there were non-asbestos fibres present that were countable by PCM, within the enclosure indicating dust was present or the enclosure purging had not been sufficient.

Site 6 was the only other site where personal monitoring fibre concentrations for 4SC analyst personal samples were above the LOD. As previously discussed, there were multiple failures for both visual inspections and disturbance air tests at this site, so it is unsurprising that measurable fibre levels were seen during these activities. The highest personal result was 0.05 f/ml for a 131 litre, 87-minute sample which included a period where dust disturbance was conducted using a brush.

4.5.2 4SC Analyst RPE use

Seventeen visual inspections were witnessed in whole or in part during the project. Nine of which lasted longer than one hour. HSE guidance (HSE 2013b), states that tight fitting ori-nasal RPE should only be worn for one hour before taking a break as wearing for longer could adversely affect the seal, and therefore the fit and protection afforded. On four out of eight occasions where the 4SC analyst spent longer than one hour in the enclosure, ori-nasal RPE was worn. Discussions between 4SC analysts and HSE scientists while on-site, suggested a range of practice by 4SC analytical companies. Some 4SC analysts suggested that full-face RPE was made available to them and they did use if required. Others stated that their company did not issue full-face RPE to 4SC analysts as standard nor had they undergone a face fit test for this type of RPE.

4.6 Fibre levels during enclosure dismantling

To properly assess the effect asbestos removal and the 4SC procedure may have on asbestos fibre levels inside a building, a final reassurance air test (post 4SC) can provide confidence to the dutyholder that the area is safe to reoccupy. Reassurance air testing was intended to provide the assurance that the 4SC procedure was effective in minimising any increase of fibre concentrations in the air, see HSG248 (HSE 2005).

The scope of this project did not include any monitoring after the 4SC procedure had been completed and the enclosure dismantled. However, it did include monitoring during enclosure dismantling. Enclosure dismantling has a high potential to disturb fibres left on surfaces or trapped by the polythene sheeting. HSE guidance in HSG247 (HSE 2006) specifies that PVA spray should be used on polythene sheeting after Stage 3 to reduce the potential for trapped fibres becoming airborne. PVA spray was only used on one site and this observation is discussed in more detail in the report to be published in conjunction with this title "The Use of Control Measures During Licensed Asbestos Removal". The PCM results for both personal and static monitoring are presented in Tables 5 and 6 in the results section.

The results show that measurable fibre concentrations were observed during this activity and the TEM analysis confirmed that some of the fibres presents were asbestos (shown in Tables 8 and 9). There were thirteen static samples taken in total and the samples were always at least 480 litres in volume and so the LOD was always 0.01 f/ml or below.

For six of the eight sites and ten out of the thirteen samples, the results were below the LOD. This indicates that fibre concentrations did not exceed the clearance indicator for enclosures on this site both before and after enclosure dismantling. It is therefore unlikely that fibre concentrations for these sites would rise above 0.01 f/ml for normal activities taking place in the areas where ACMs had been removed. Once the containment is removed dilution and dust settling factors should reduce fibre concentrations to previous background levels.

Three samples gave results between 0.012 f/ml and 0.015 f/ml. One sample was taken on Site 1 and two on Site 8. On both sites these concentrations were higher than during the clearance air testing for these sites. This suggests that the enclosure dismantling activities disturbed more fibres than the brushing that took place during clearance testing. This could be evidence that the brushing did not adequately disturb fibres on all surfaces or that enclosure design included areas where fibres could be trapped. Given that these results were not significantly above 0.01 f/ml it would again be expected that over time fibre concentrations would be diluted and reduce to background levels.

Airborne fibre concentrations following the 4SC completion and enclosure dismantling, will dilute from the clearance indicator (<0.01 f/ml) but the rate of dilution to background airborne fibre concentration and the varying factors that would affect the dilution have not, currently, been measured. This would require a further investigation and sampling exercises which would involve long sampling periods in the days and weeks after a 4SC.

On Site 6, static sampling was carried out after the 4SC for enclosure 1 before HSE arrived on site to assess the 4SC for enclosure 2. Enclosure 1 was adjacent to enclosure 2. There were two days between the completion of the 4SC and the first sample being taken by HSE. This is only a small set of samples, and the results cannot be considered statistically significant but they do give an indication of what can be expected in terms of asbestos fibre concentrations after a 4SC. Thirteen samples were taken in total across a fifteen-day period. Sampling took place during the day and no sampling took place on Sundays. On one day, two samples were taken. Samples ranged in volume from 932 to 2435 litres giving LODs between 0.002 and 0.005 f/ml.

The full set of results for both PCM and TEM analysis can be found in Tables 7 and 10. Two samples gave PCM results above the LOD with results of 0.003 f/ml and 0.005 f/ml. One sample was too occluded by particles to count (this is more likely to occur when taking large volume samples). Six samples were analysed by TEM with three showing the presence of asbestos fibres and two giving measurable asbestos fibre concentrations of 0.004 and 0.006 f/ml.

These results show a consistent fibre concentration level below 0.01 f/ml and in most cases a level well below this. Some reinstatement work took place during the sampling period including painting steel beams and electrical work. These activities have the potential to disturb any fibres left behind on surfaces. Work was carried out throughout the sampling including on the day the higher results were recorded but no specific conclusions could be reached. Where there are suspicions that airborne asbestos fibre levels may persist due to the nature of the ACM, reinstatement and other works should be subject to a further risk assessment for that activity with suitable control measures employed. This applies to ongoing works by contractors or when the dutyholder takes back control of the area.

4.7 Certificate of Reoccupation reviews

CfRs were reviewed from several sites and were found to be generally compliant with HSE guidance. However, some deviations from HSG 248 (HSE 2005, at the time) were identified in all CfR examined. The CfRs were generated by either database systems or spreadsheets and some but not all included photographs in advance of the new requirements published by HSE in 2021 (HSE 2021), which specified the use of photographic evidence. All CfRs were uniquely identified and contained the laboratory, client and LARC details. All stages were recorded as having passed or failed as appropriate and the required supporting information was recorded. However, there were still some differences in the design of the CfRs. Some were standalone documents of a few pages, whereas one had a two-page CfR but the Stage 3 results were on the 39th page of a 56-page report (this report included all leak testing associated with the report and the other failed CfR's). This approach does not assist dutyholders in fulfilling their diligence checks of the CfR. Some CfRs did not have page numbering, which also makes them difficult to collate when paper records are used. The CfRs examined were collected from site or shortly afterwards and changes may have been made after quality control checks by the 4SC analytical company, LARC or dutyholder. The certification discussed below has been split into Stages 1 to 4.

Stage 1: The Stage 1 sections of the CfR were fully completed and the records were clear, allowing for spelling and grammatical errors. Most Stage 1 sections were completed in quite short times considering the size of some of the sites and varied from 10 minutes to 93 minutes. As the 4SC analyst had been on site for the duration of the project it is assumed they had already assessed the LARC plan of work and were therefore just checking for amendments in this time. On one site, the 4SC analyst did not repeat the Stage 1 after an initial Stage 2 failed (see Figure 7) this is not in line with HSG 248 guidance as Stage 1 should be repeated (enclosure breaches, waste / transit route contamination can occur in the intervening period which was the next day in this instance). For Stage 2 visual inspections lasting several days, HSE guidance for analysts does not currently recommend a daily pre-visual Stage 1 to check enclosure integrity, clear waste and transit routes.

Stage 1 of 4: Preliminary check of site condition and job completenesss			
Plan of work checked to confirm areas to be assessed			N/A
State 'YES' if the following are intact and operating correctly (record any deviations in the comments section below)			
Work areas			N/A
Enclosure/air extraction			N/A
Hygiene facilities			N/A
State 'YES' if the following areas and their immediate surroundings appear to be free from obvious asbestos debris and asbestos waste sacks (record any deviations in the comments section below)			
Skip area/waste route			N/A
Transit route			N/A
Enclosure/work area[1]			N/A
1. *There should be no unnecessary equipment within the enclosure. Where there are no or insufficient viewing panels this should be recorded and the assessment continued.*			
Completed Previously	**Time:** 10:01	**Date:** 03 May 2019	**Assessed b**[redacted]
Comments: N/A			
Signature of assessor: [redacted]			

Figure 7: Excerpt from the Certificate of Reoccupation for Site 7 following a Stage 2 fail stating that Stage 1 had been "completed previously". This stage should have been repeated as per HSG 248 (HSE 2005).

Stage 2: Stage 2 visual inspections failed four times in the eleven enclosures. The details of the failed visuals were all recorded in the Stage 2 sections of the CfR. Some had the CfR as a standalone document, whilst others had a single document, which contained all the CfRs for an enclosure (both passed and failed) as well as other associated air monitoring reports. For the standalone CfRs, some of the 4SC analysts recorded it as a second CfR for an enclosure following a failed one, whilst others did not. From a traceability perspective it would be useful for separate documents to state that this is the repeated visual inspection although it is not currently a requirement. Some of the timings of the visual inspections were inconsistently reported, the excerpt below (Figure 8) shows the time and date between Stages 1 and 2 being completed on 14/12/2018 which does not correspond with the recorded visual inspection time of 30 hours. Issues like these can be due to the software being used and this needs to be fit for purpose. The visual time recorded by HSE scientists on-site verified the 30-hour visual time recorded.

Stage 1 of 4 - Preliminary Site Assessment		COR Start Time : 8:34
Plan of Work	√	Revised plan of work reflects on site conditions.
Location of asbestos removed	√	Enclosure 2, [redacted]
Type of ACMs removed	√	Asbestos Sprayed Coating (Amosite).
Any remaining ACMs	√	Refer to comments.
Enclosure and airlocks are clean and intact where visible	√	Air/baglocks, enclosure & NPU modular pods appear clean and intact.
Enclosure has sufficient light and access equipment	√	Enclosure has sufficient lighting and access equipment.
All waste bags have been removed from enclosure	√	All waste bags removed satisfactory.
Air extraction equipment is in situ and operating	√	NPU's insitu, operational & vented to atmosphere.
Hygiene facilities are intact and operable	√	DCU's 1 & 3 are intact, operable and sited correctly.
Transit & waste route & areas surrounding enclosure are clean	√	Transit / waste routes & surrounding areas appear clean refer to comments.
Viewing panels present	√	Present along with CCTV & suitable for the viewing of entire enclosure.
Potential hazards inside the enclosure	√	Refer to [redacted]

Transit and Waste Route Locator

Transit / waste routes exit the three stage air/baglock systems situated external of enclosure within the 1st floor open plan office area, then travel to ground level via corresponding lift lobby area to the main central stairwell. Once at ground level proceed through fire escape doorway to the designated skip & DCU's located within the main carpark heras fenced compound.

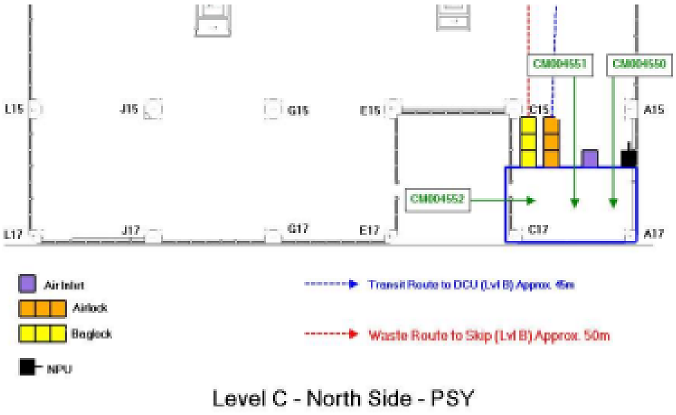
Stage 1 Pass	Date	Time	Analyst	Signed :
√	14/12/2018	08:56	[redacted]	[redacted]

Stage 2 of 4 - Thorough Visual Inspection		
	Confirm	Comments
Airlocks and enclosures are free of waste bags	√	Air/baglocks, enclosure & NPU modular pods free of waste bags.
Evidence of lock-down sprays	x	None evident also refer to 1st stage comments.
Enclosure is dry	√	Enclosure was suitably dry at time of inspections.
All ACMs have been completely removed from underlying surfaces	√	All targeted / specified acm's removed AFARP refer to comments.
All surfaces are free from dust and debris	√	Further cleaning required at analyst request.
Any excluded areas not part of visual inspection	√	Refer to all comments.
Any remaining ACMs present, sealed, labelled or photographed	√	Refer to all comments.

Stage 2 Pass	Date	Time	Duration	Analyst	Signature
√	14/12/2018	09:23	30h03	[redacted]	[redacted]

Figure 8: Stage 2 started at 08:56 14/12/2018 and finished at 09:23 14/12/2018, but the visual inspection time is recorded as 30-hours 3 minutes.

Some Stage 2 comments were more expansive than others and in cases where asbestos or bulkheads were to remain in the enclosure after the 4SC either a separate drawing or annotations to the site drawing would have clarified the situation for the dutyholder to effectively manage any remaining ACM’s. This can also be seen in some of the Stage 3 diagrams. None of the Stage 2 comments referred to whether the completed work was suitable and sufficient to satisfy the clients scope of works or specification. This is a key aspect to ensure that the potential for exposure in follow-on work is minimised. As the 4SC analysts were employed by the client, in all but one case, there is no reason to suspect the scope would not have been available to them.



ACM's remain in the area but these are not detailed on the drawing. The drawing is compliant but it would be beneficial for the duty holder to clearly identify the locations as per HSG 248 version 1

Stage 2 of 4: Thorough visual inspection		
State 'YES' if the following requirements are met (record any deviations in the comments section below)		
Airlock/ baglock / enclosure free from waste bags, materials and unnecessary equipment	Yes	
All ACMs have been completely removed from the underlying surfaces	No	
Interior surfaces inside the enclosure are free from debris and fine settled dust	Yes	No enclosure dimensions just
Volume of the work enclosure	180m³	volume recorded

PASSED **Time:** 13:44 **Date:** 03 May 2019 **Duration of Inspection:** 207 mins **Assessed b**[redacted]

Comments: Floor (apart of the exposed section approx. 0.5 m away from the perimeter wall), breeze block partition walls (apart of the sections extending into the high level duct) were sheeted out from the enclosure. 2 No. Risers (17 A/C) were wire brushed, hoovered and wiped, horizontal connecting ducts have been removed and surrounding areas wire brushed, hoovered and wiped.
Cleats above the spandrel panels have been cleaned and encapsulated, gaps/inaccessible areas to the spandrel panels and windows have been visually inspected and then sealed with tape. The imbedded AIB packers to the tops and bottoms of the risers have been encapsulated and will form part of the future removal works. Due to porous nature of the EML floors/ceilings of the risers they have been cleaned, visually inspected and sealed with corex as a precaution and will form part of the future removal works. During the visual inspection ACM's were identified between the tops of the spandrel panels and concrete walls (in between the cleats), due to the inaccessibility following the encapsulation those areas have been sealed out with corex and will form part of the future removal works.

Generally good comments but it would be useful for the duty holder to be able to locate bulkheads remaining in

Asbestos to remain: situ & remaining ACM's that will need to be assessed, added to the asbestos register and managed

Layer between the screed and concrete slab, small section of vinyl tiles and bitumen adhesive below to the floor which will form part of future screed removal works. AIB packers/shuttering adjacent to the riser floors and ceilings which have been encapsulated.

Figure 9: Stage 2 with some good descriptive elements which would have been enhanced by an extra drawing (notes in blue from HSE scientists).

Stage 3: All Stage 3 documents reviewed, included the minimum number of sampling pumps required, the brushing time, the brushing method, and a record that the NPU was switched off. There was a drawing with the pump positions, however, quality was variable, and they were generally an annotated LARC drawing rather than their own drawing. Several issues were identified in the site drawings, Figure 9 above shows the drawing with the volume of the enclosure, but not its dimensions as required by HSG 248 (HSE 2005) it also means that the dutyholder cannot use the equation [$A^{1/3}$-1] to check the number of pumps used as neither the height of the enclosure nor the area is known. One of the database systems used by 4SC analysts to generate CfRs erroneously includes the field blank as a sample. This is misleading when looking at brush disturbance times (1.5

minutes per sample). The microscope reference was also missing off this CfR. Figure 10 shows a drawing where the addition of the sample numbers had obscured some of the enclosure and where the transit route, waste route and skip labels were missing. There was also part of sample 2's unique designation missing. Another CfR did not have space on the CfR to record the number of the stage micrometer or the test slide. All the CfRs stated a brush had been used for disturbance when a broom is much more ergonomically suited for enclosures >20m^2 (as stated in HSG 248, HSE 2005) which most of the enclosures were. This shows either inaccuracy in recording or that the risk assessment has failed to take the ergonomics of using a brush rather than a broom into account. For one Stage 3 requiring five sampling pumps, all were started at the same time (9:25) in a 252 m^2 area and then had their flow measured, were turned off and collected all in the same minute so they finished at 10:36. Fibre counting times were within acceptable limits.

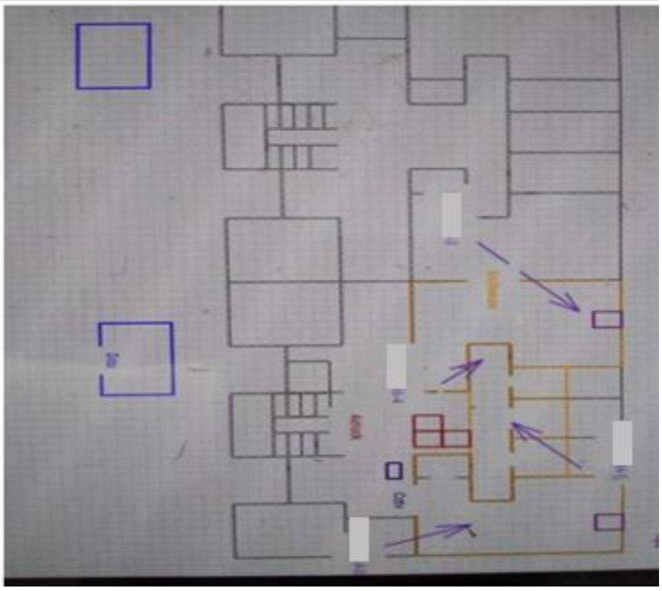
Enclosure Height (m)	2.80
Enclosure Area (m²)	48
Number of samples being taken	2 4 Samples taken not 2
Stage Start Time	14:51:03
Stage End Time (set upon completion)	16:24:03
Enclosure Sketch The drawing has the area but not the enclosure dimensions and the transit and waste routes are missing. The placement of sample numbers obscures some of the enclosure limits. Sample 2 is cut off at the edge and is missing part of its unique identifier	

Figure 10: Stage 3 drawing that does not contain sufficient information and is not suitably clear to show the enclosure limits. (see HSE notes in blue)

Stage 4: The Stage 4 sections of the CfRs were all completed in line with the CfR templates (in HSG 248, HSE 2005) but the supporting notes and comments varied significantly. The satisfactory completion of the dutyholders initial scope of work was not referred to in any of the CfRs, although several referred to the work being as described in the LARC plan of work. However, this is not always the same thing and the reason for the removal work, often to enable other work, may not have been achieved. Figure 11 shows a comment referenced in Section 4.2.3 of this report, where uncapped scaffold towers noted by HSE scientists during the visual inspection were disposed of as asbestos waste at Stage 4. It is unclear whether the 4SC analyst planned this or reacted to discussions with HSE scientists. Stage 4 inspections were generally completed the following day so there was sufficient time for the work to be completed to a satisfactory standard. Reassurance samples were sometimes taken during and after Stage 4 by the 4SC analyst, however, no results were found to be elevated above 0.010 f/ml.

Stage 4 of 4: Assessment of site for reoccupation (after removal of enclosure)	
State 'YES' if the following requirements are met (record any deviations in the comments section below)	
Former work enclosure and the immediate surrounding area are free from any visible debris, asbestos waste bags and waste.	Yes
Transit route and waste route are free from any visible debris, asbestos waste bags and waste.	Yes
All ACMs in the scope of work have been removed and any known ACMS remaining are intact.	No
PASSED **Time:** 08:00 **Date:** 07 May 2019	**Assessed b**[redacted]
The area can be reoccupied.	
Comments: All aspects of the former enclosure have been dismanteled and disposed of as waste. DCU to remain on site. It has been identified that specific vertical scaffold tower poles have been uncapped on the top and therefore wrapped and disposed off as waste. Asbestos to remain: Please see stage 2 comment section of this report.	
Signature of assessor: [redacted] Good comments regarding scaffold pole disposal where ends had not been capped	

Figure 11: Scaffold poles that were uncapped during Stage 2 were disposed of as potentially contaminated.

5 Conclusions

The conclusions regarding HSE scientists' observations of the 4SC process during this study are as outlined below.

- there were significant improvements in the way that 4SC analysts conducted the 4SC compared to the previous HSE study in this area (HSE 2018).
- the LARC Supervisors' visual inspections prior to handover to the 4SC analyst had improved, but there was still room for further improvement. This is a recognised focus in the industry.
- enclosure Handover forms were available at five out of eight sites and all of the later sites when LARCs were more aware and had the opportunity to introduce them.
- there were no Stage 1 failures, which means the LARC and the 4SC analysts' assessment of site readiness was well aligned and generally concurred with HSE scientist's observations.
- the Stage 2 visual inspection can often take longer than planned and the 4SC analysts' choice of RPE and rest / break regime should take this into account. The choice of ori-nasal RPE for some of the visual inspections by 4SC analysts led to some exceeding the 60-minute guidance limits on ori-nasal RPE detailed in HSG 53.
- the inspection of equipment remaining inside the enclosure by the 4SC analyst did not always include a thorough inspection of mobile scaffolds, NPU's and other equipment.
- 4SC analysts need to be aware of LARC equipment management regimes after Stages 1, 2 and 4. This needs to be controlled more stringently for items that are difficult to clean and to ensure that they have been being correctly bagged before being taken out of the enclosure.
- the 4SC analyst needs to ensure that if further cleaning is required inside the enclosure, that they leave the enclosure and fail Stage 2.
- the 4SC analysts brushing times and methodology at Stage 3 of the process needs to ensure that minimum times are completed. A brush or broom must be used and that the brushing is sufficient to release fibres from the polythene sheeting and surfaces around the sampling point. Brooms (long handled brushes) should be used in enclosures >20m^2 to reduce the associated ergonomic risks and potential for tearing of coveralls of the 4SC analyst (eg working on their hands and knees or climbing on ladders to brush ceilings).
- the witnessed failure rate of enclosures was higher than would normally be expected compared to information supplied by the industry. However, as the statistical sample was small, no firm conclusions can be drawn. This is an area that requires further monitoring to collect data for further analysis.
- reassurance air testing during enclosure dismantling was infrequently carried out and the process would benefit if these were carried out more consistently at Stage 4. Reasons for not undertaking reassurance air testing should be robust and recorded on the CfR, this would help affirm to the dutyholder that the area is fit for reoccupation.

- reassurance air testing conducted by HSE Scientists after asbestos removal did show some asbestos fibres in the air and the numbers of fibres varied. However, no firm conclusions could be drawn as there were only fifteen results gathered and a definitive reason for the variation could not be identified.
- the differences between PCM and TEM measurements are complex, particularly at low asbestos concentrations. There was insufficient data from this small-scale study and results did not indicate that one method gave consistently higher or lower result than the other. Further work could provide greater clarity on the relationship between the techniques but would require care when selecting parameters and methodology.
- the CfRs examined identified that they were generally compliant with HSE guidance. However, from a technical perspective, errors were present in all CfRs examined.
- examination of the CfRs identified some practices that were not in-line with HSE guidance at the time. Examples of these are not repeating Stage 1 after Stage 2 had failed; and insufficient clarity in the report to ensure that the dutyholder is able to correctly interpret or extract important information, particularly with respect to any ACM’s left in the enclosure.

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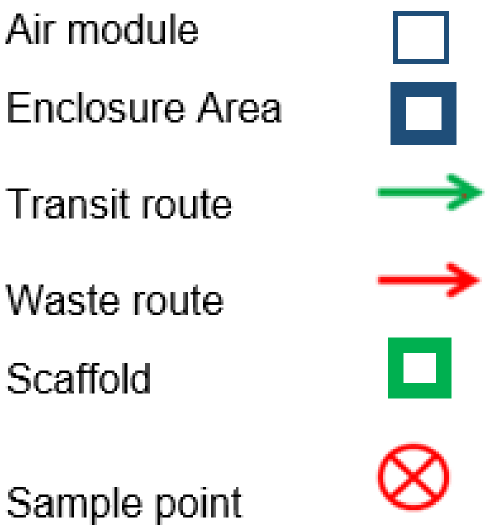
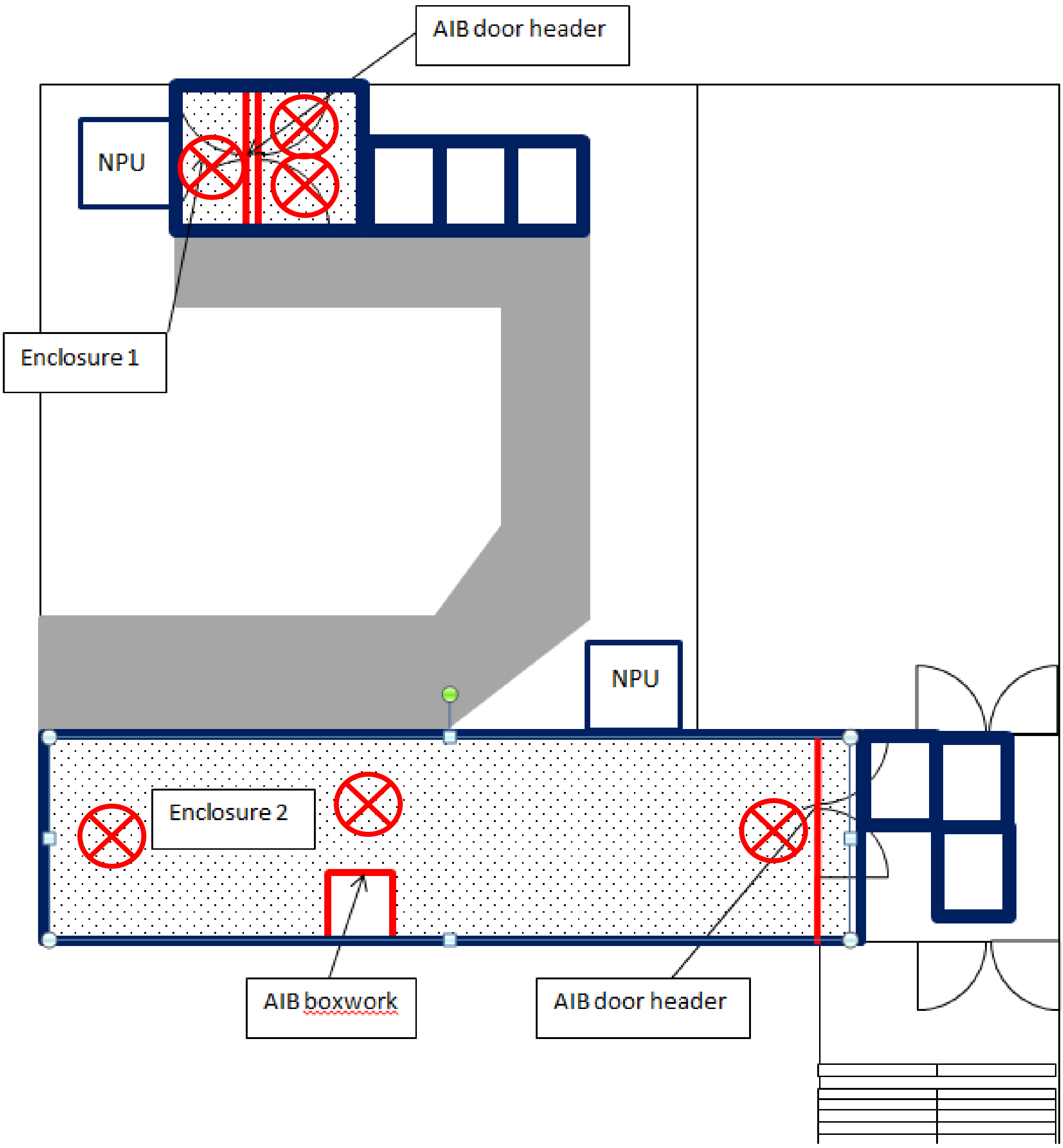
7 Appendix A

7.1 Enclosures and work areas for the eight site visits

Key for All Enclosure Diagrams



7.1.1 Site 1



Key for All Enclosure Diagrams

Air module

Enclosure Area

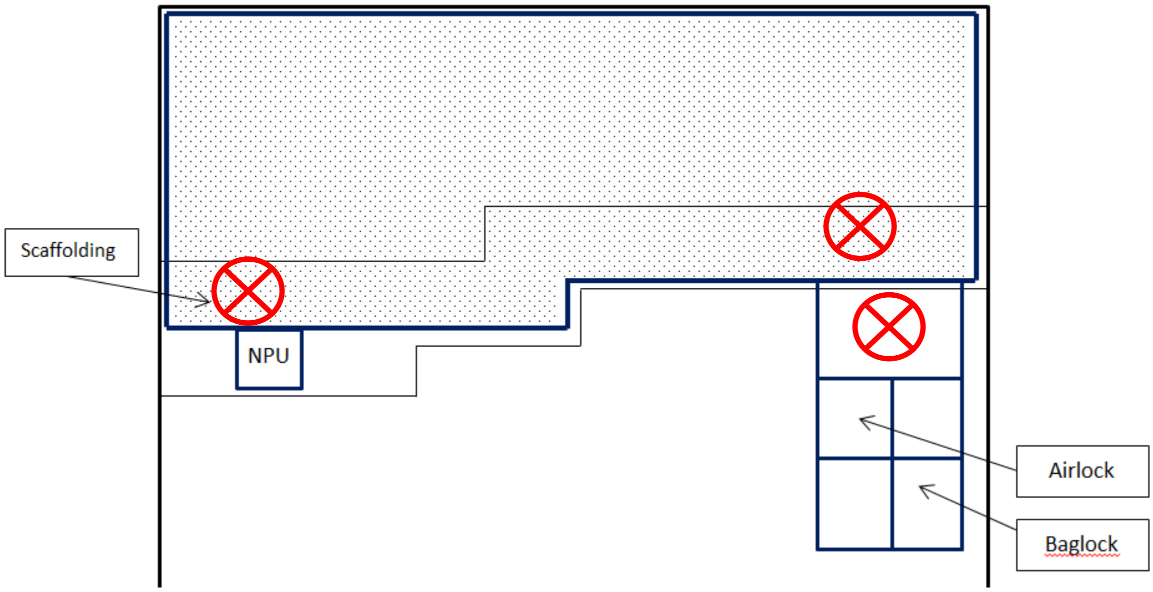
Transit route

Waste route

Scaffold

Sample point

7.1.2 Site 2



Key for All Enclosure Diagrams

Air module

Enclosure Area

Transit route

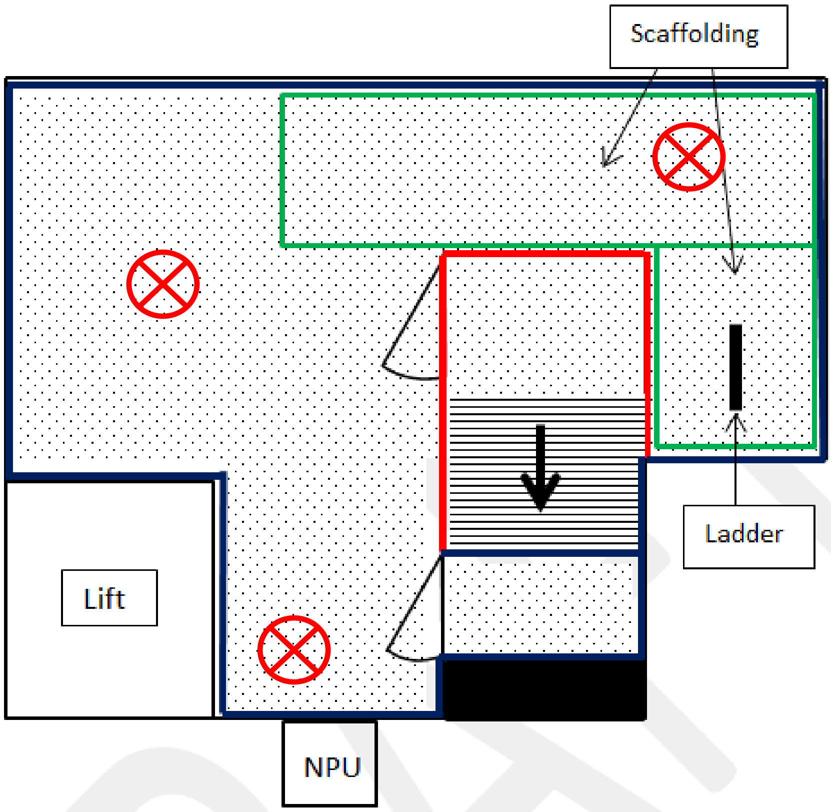
Waste route

Scaffold

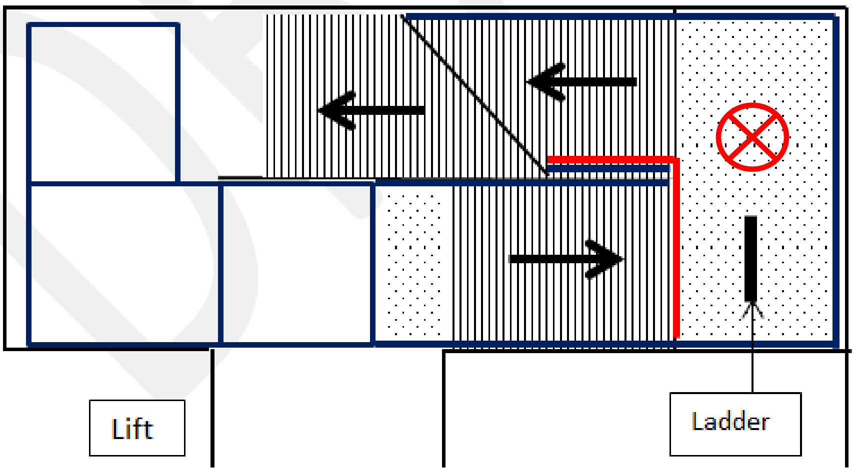
Sample point

7.1.3 Site 3

4th Floor



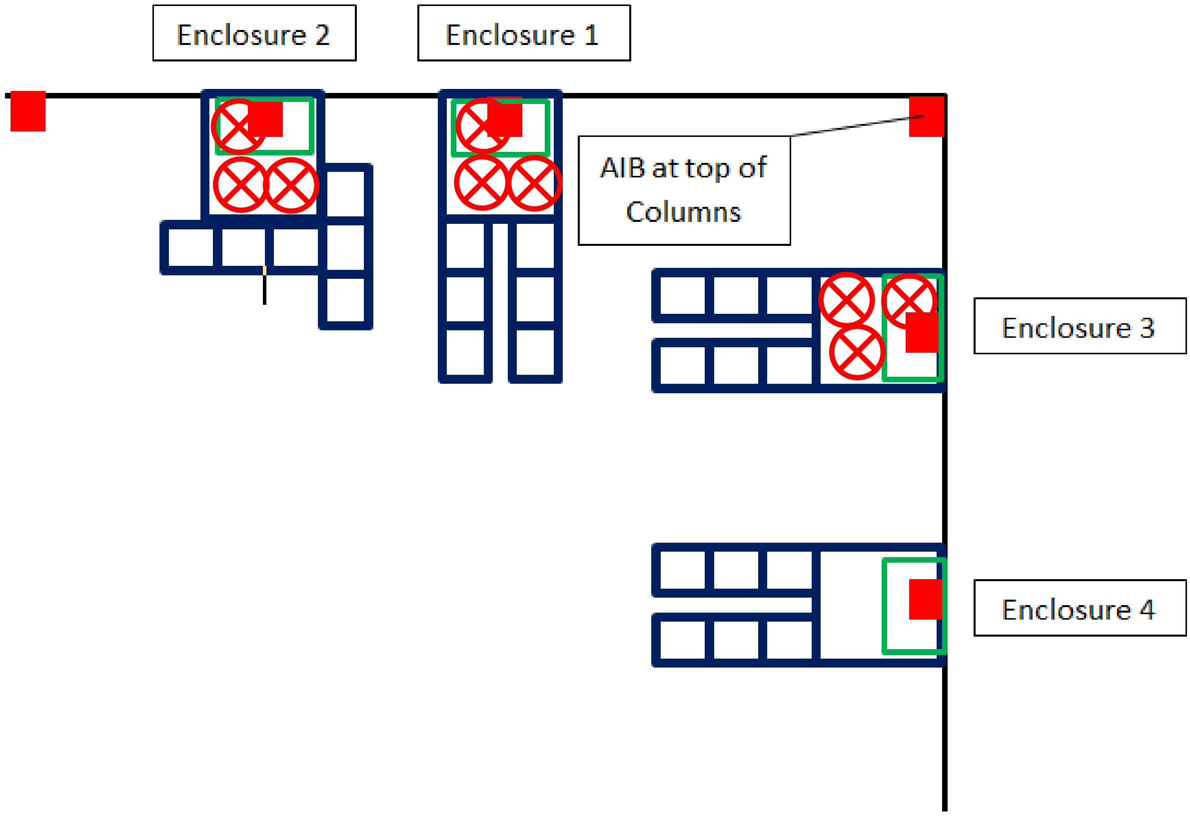
3rd Floor



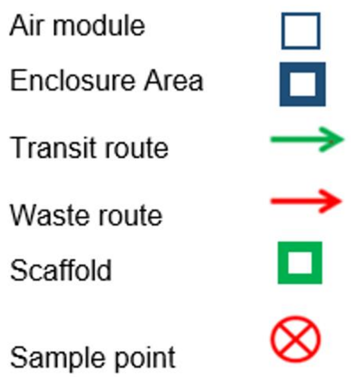
Key for All Enclosure Diagrams

- Air module
- Enclosure Area
- Transit route
- Waste route
- Scaffold
- Sample point

7.1.4 Site 4

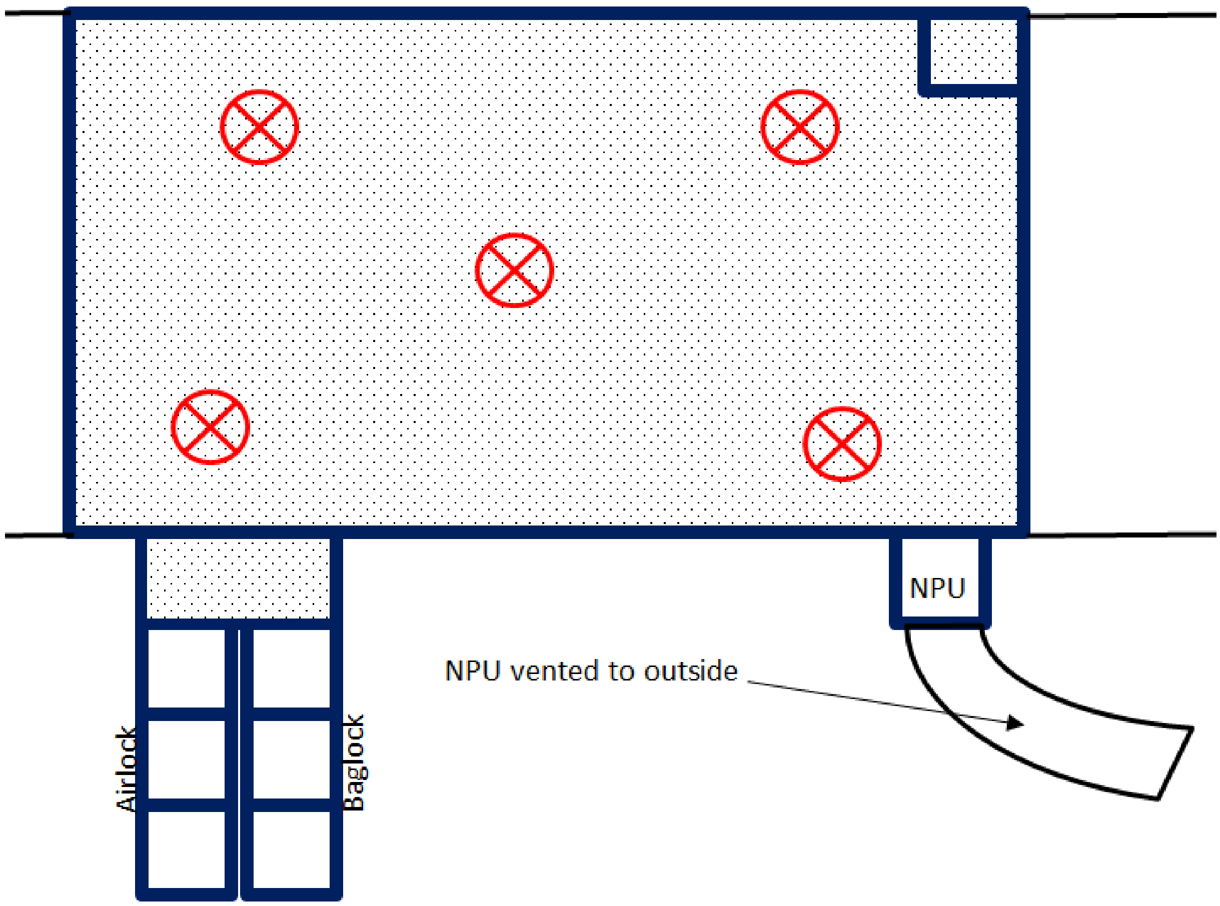


Key for All Enclosure Diagrams



7.1.5 Site 5

AIB ceiling throughout enclosure



Key for All Enclosure Diagrams

Air module

Enclosure Area

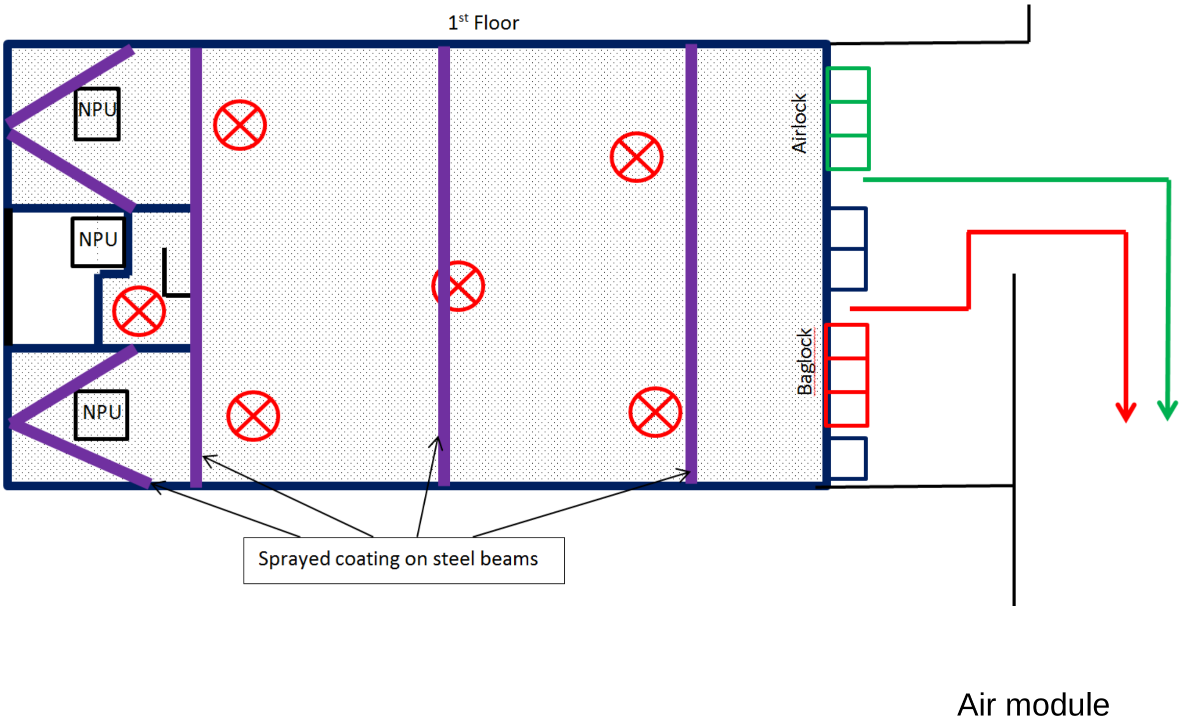
Transit route

Waste route

Scaffold

Sample point

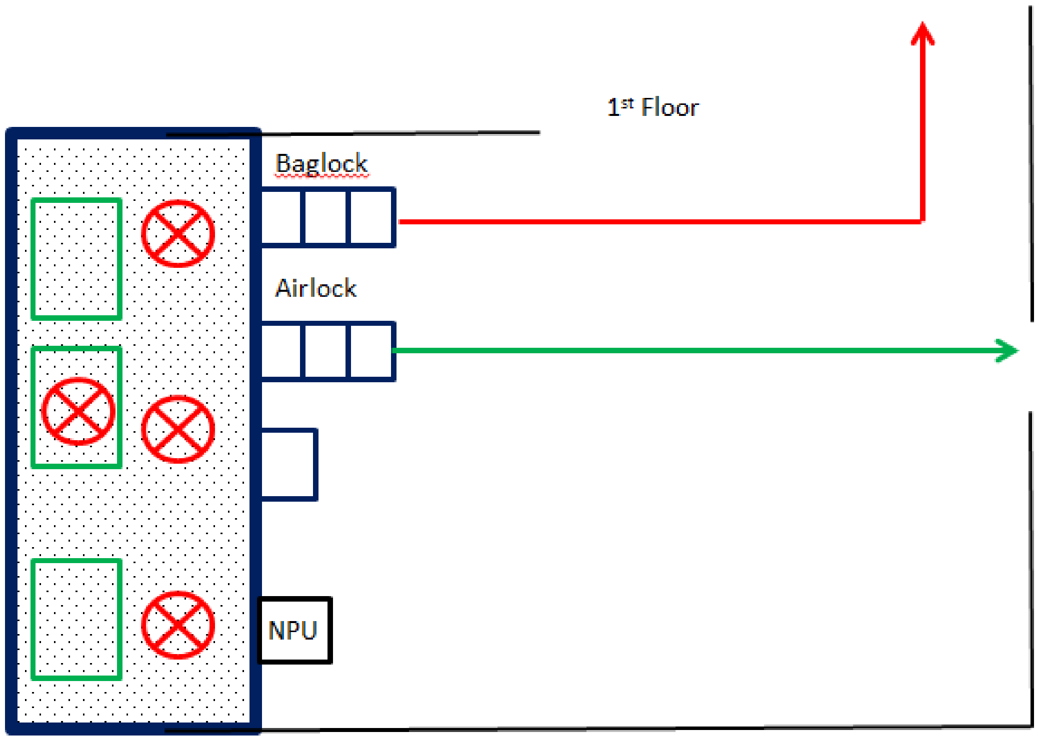
7.1.6 Site 6



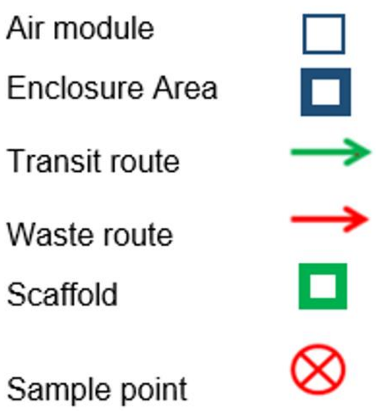
Key for All Enclosure Diagrams

- Air module
- Enclosure Area
- Transit route
- Waste route
- Scaffold
- Sample point

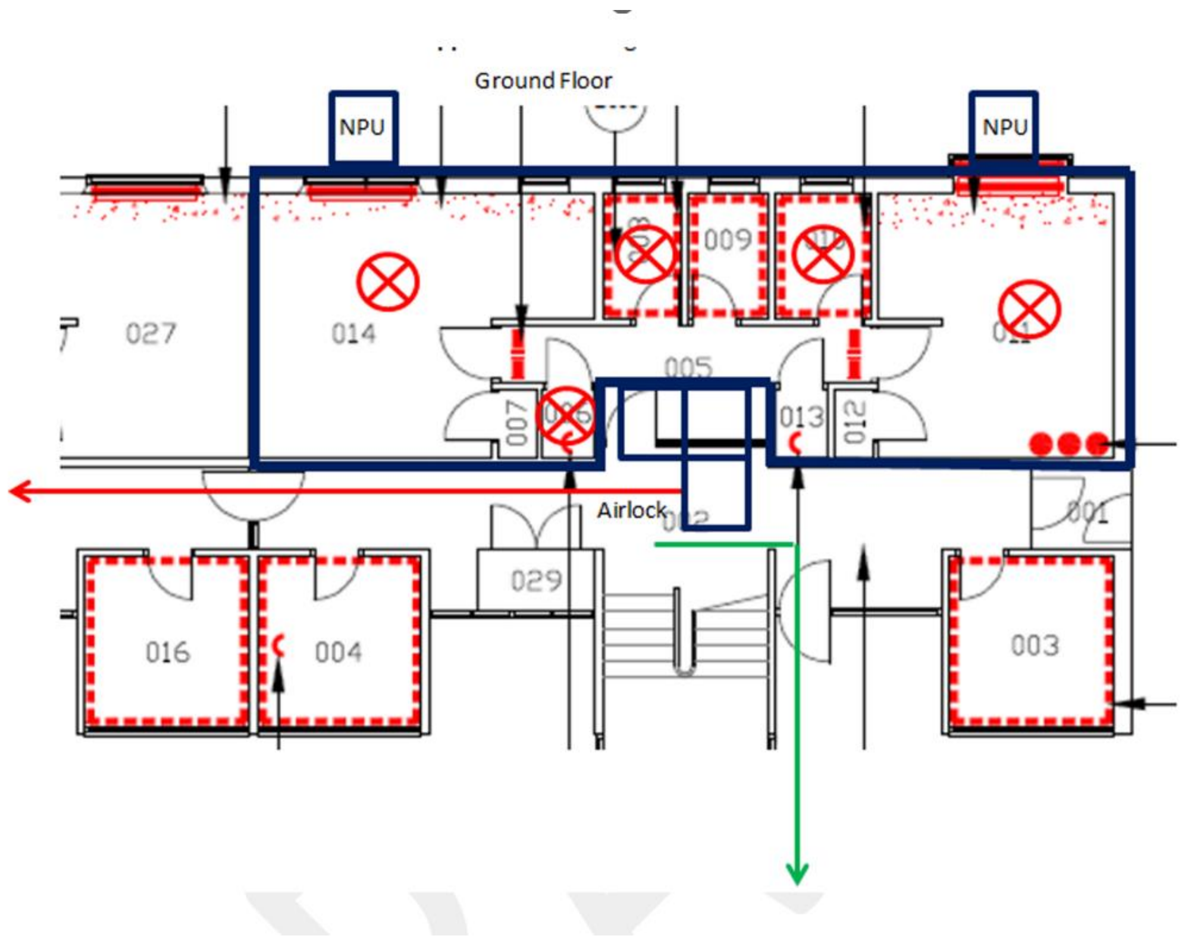
7.1.7 Site 7



Key for All Enclosure Diagrams



7.1.8 Site 8



Key for All Enclosure Diagrams

Air module

Enclosure Area

Transit route

Waste route

Scaffold

Sample point

Glossary

4SC	Four-stage clearance
AIB	Asbestos Insulating Board
APF	Assigned Protection Factor
ACM	Asbestos Containing Material
ACOP	Approved Code of Practice
ARCA	Asbestos Removal Contractors Association
ACAD	Asbestos Control & Abatement Division
CAR	Control of Asbestos Regulations 2012
CCTV	Closed Circuit Television
CfR	Certificate of Reoccupation
DCU	Decontamination Unit
FOD	Field Operations Division
GB	Great Britain
LARC	Licensed Asbestos Removal Contractor
LoD	Limit of Detection
LoQ	Limit of Quantification
NFDC	National Federation of Demolition Contractors
NPU	Negative Pressure Unit
PCM	Phase Contrast Microscopy
PCME	Phase Contrast Microscopy Equivalent
QC	Quality Control
RPE	Respiratory Protective Equipment
TEM	Transmission Electron Microscopy
TWA	Time Weighted Average
UKAS	United Kingdom Accreditation Service
WHO	World Health Organisation

The importation and use of asbestos in Great Britain (GB) was banned by 1999. However, asbestos can be present in buildings constructed or refurbished before 2000 and continues to be removed as part of ongoing risk management. Only HSE licensed asbestos removal contractors (LARCs) can undertake higher-risk removal work. Confirmation that the area can be reoccupied is undertaken by accredited 4-Stage Clearance (4SC) organisations. This research aimed to assess whether standards had improved and whether there was compliance with HSE guidance (HSG248, 2005 version) during 4SC. HSE researchers observed work practices of 4SC analysts at eight licensed asbestos removal sites and collected air monitoring samples, between 2016 – 2019. As the findings below represent work under HSE observation they may not be representative of unobserved practice:

- certificates for reoccupation (CfR), were issued at all sites but were not always clear, unambiguous and accurate.
- industry integration of HSE recommendations from previous work (HSE 2018) was observed at five sites.
- an improvement in the application of the 4SC process was observed compared to previous studies (more failures were correctly identified).
- reassurance air monitoring carried out by HSE scientists after stage 3 had elevated fibre concentrations. This is optional in guidance and was not conducted by any 4SC analysts.
- HSE guidance (HSG248) was not always followed:
    - when selecting and using Respiratory Protective Equipment (RPE).
    - when LARCs were required to undertake additional cleaning (analysts remained in the enclosure).
    - when undertaking dust disturbance activities.

These findings will help to inform HSE's intervention approach.

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