EFFECTIVENESS OF SAFETY EQUIPMENT AUSTRALIA SE400AT POSITIVE-PRESSURE DEMAND FILTERING DEVICE DURING ASBESTOS REMOVAL OPERATIONS

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EXECUTIVE SUMMARY

There was no evidence of asbestos fibre leakage into SE400AT facepieces on 50% of wear periods.

The SE400AT positive pressure powered filter device exhibited a 95th percentile Workplace Protection Factor 2,600 when worn by contractor's employees during asbestos removal operations.

It is therefore concluded that an Assigned Protection Factor of 2,000 could validly be assigned to the SE400AT model evaluated in the Workplace Protection Factor study reported herein.

1 INTRODUCTION

Until recently the selection of Respiratory Protective Equipment (RPE) in the UK was based on assuming that the Nominal Protection Factors (NPF) specified in the relevant UK or European (CEN) standards were achieved in real workplaces when the RPE were correctly worn by suitably trained and supervised wearers, e.g. HSE (1990). However, an extensive series of publications since the late 1970s has demonstrated that the performance of RPE in real workplaces is almost invariably substantially lower than observed during standard laboratory tests, e.g. Moore & Smith (1976), Myers & Peach (1983), Myers et al (1984), Shackleton et al (1985), Colton et al (1990a,1990b), Howie & Simpson (1991), Tannahill (1991), Howie et al (1996). For example, three studies have examined the performance of full-facepiece tight-fitting filter devices used during the removal of Asbestos-Containing Materials (ACM): two studies on powered devices, Howie and Simpson (1991), Howie et al (1996) and one study on unpowered devices, Tannahill (1991). The single figure index derived from Workplace Protection Factor (WPF) results is the 95th percentile, i.e. the Protection Factor (PF) achieved by 19 wearers out of 20. The 95th percentile results for these three studies are summarised below:

Device - NPF (Reference)	**Laboratory Protection Factor**	**Workplace Protection Factor**	**Comment**
Powered - 2,000			
Howie & Simpson (1991)	> 100,000	<< 500	one device
Howie et al (1996)	> 10,000	38	four devices
Unpowered - 1,000			
Tannahill (1991)	> 10,000	28, 68, <17	three devices

From the above it can be seen that both the powered and unpowered devices gave substantially poorer performance in the workplace than in the laboratory, e.g. in the Howie et al (1996) study the WPF was < 1/250th of that observed in the laboratory.

Given the extensive literature on the reality of RPE performance in the workplace British Standard Specification 4275:1974 on the selection, use and maintenance of RPE was revised to reflect such information. The revised BS 4275 was published in 1997. RPE in the UK is now selected on the basis of Assigned Protection Factors (APF) derived from observed performance demonstrated in real workplaces when worn by wearers carrying out their normal duties, BSI (1997), HSE (1998).

The consequence of selecting RPE on the basis of APF is that the assumed levels of performance have been very substantially reduced for all nominally high-performance

devices. For example, the assumed PF of conventional full-facepiece powered respirators fitted with P3 filters has been reduced from 2,000 to 40. The maximum airborne asbestos fibre concentration in which such devices are assumed to provide "adequate" protection in crocidolite (blue) asbestos, amosite (brown) asbestos or chrysotile (white) asbestos has been reduced from 2,000 times Control Limit concentration to 40 times Control Limit Concentration. That is, in crocidolite or amosite with a Control Limit of 0.2 fibres/ml, the maximum use concentration has been reduced from 2,000 x 0.2 = 400 fibres/ml to 40 x 0.2 = 8 fibres/ml.

As such respirators are effectively the "standard" device worn during remediation or removal of asbestos-containing materials (ACM) the consequences on how such work is carried out has been substantial as much greater care is required to restrict ambient concentrations to the current maximum use concentrations.

The SE 400 positive pressure demand filter device is a novel item of equipment. Consequently, no workplace protection factor studies have been undertaken and no Assigned Protection Factor has been set for such devices.

It has therefore been necessary to evaluate the performance of the SE 400 device in real workplaces.

2 STUDY OBJECTIVE

A Workplace Protection Factor study was carried out with the object of determining the performance achieved by the SE 400 positive pressure demand filter device when worn by asbestos removal contractors' employees during removal of asbestos-containing materials.

3 DESCRIPTION OF SE400 POSITIVE-PRESSURED DEMAND FILTER DEVICE

The SE 400 device consists of a belt-mounted fan, filter and battery unit which is connected by a breathing hose to a full-facepiece fitted with a demand valve and an inner-cup - Figure 1. The fan is controlled by the demand valve on the facepiece so that the fan motor immediately speeds up if the in-facepiece pressure falls below +20 Pa during inhalation. The fan can supply peak flow rates >450 l/min when the device is fitted with particulate filters. The SE 400 is fitted with an in-facepiece microphone and an external loudspeaker box to ensure clear voice communication without lifting the facepiece - Figure 2. The SE 400 can operate in the negative pressure mode to permit safe exit from a contaminated area.

The SE 400 is fitted with audible and visual warning devices which alert the wearer if: the respirator has not been correctly set up, e.g. if fitted with a flat battery; if the facepiece is removed while the device is running; if the pressure in the facepiece goes negative during two consecutive breathes; if the battery pack has run down (the warning is given at least 5 minutes before the battery runs flat) and when filters should be changed. All above events, and time of occurrence, are stored in an integral memory in the belt unit. Contents of the memory can be down-loaded to a computer to provide a record of usage and any failures.

4 AIRBORNE ASBESTOS FIBRE SAMPLING AND ANALYSIS

4.1 Airborne asbestos fibre sampling

Asbestos fibre sampling is carried out by drawing air through a suitable sampling filter fitted in a sampling head. Personal sampling heads are generally worn on the lapel.

Conventional asbestos sampling heads are about 30 mm diameter by about 80 mm long and are fitted with 25 mm diameter sampling filters. The standard asbestos sampling heads can weight up to 200 g.

Air flow through the sampling filters is achieved using personal sampling pumps. Such pumps generally weigh 1 - 2 kg.

4.2 Airborne asbestos fibre analysis

After sample collection, the sampling filter is removed from the sampling head, placed on a glass microscope slide, rendered transparent using acetone vapour and mounted between the glass slide and a coverslip using glycerol triacetate (triacetin).

After clearing and mounting the sampling filters are analysed by manual phase contrast optical microscopy using a 400 times microscope fitted with a Walton-Beckett graticule.

Only fibres longer than 5 micrometers (μm), less than 3 μm in diameter and with length to diameter ratios (aspect ratios) > 3:1 are counted. A countable fibre with only one end inside the graticule is counted as a half fibre.

Asbestos fibre counting is highly subjective. Optimum fibre counting accuracy is achieved only if the density of fibres on the sampling filter lies between about 100 and 400 countable fibres per square millimetre (mm^2). In many asbestos removal situations a significant proportion of the airborne material is non-fibrous. Such material can obscure the analyst's field of view and cause errors. All filters with more than $1/8^{th}$ of the graticule obscured by non-fibrous should be rejected. Given that the asbestos content of most asbestos-containing materials is less than about 40%, obscuration of fibres by non-

fibrous particulates is common during work with asbestos-containing materials which may be up to 40 or 50 years old and contaminated with soot or other materials.

In practice, fibre numbers may be undercounted on dense filters and overcounted on sparsely loaded filters. In Workplace Protection Factor studies in asbestos each individual wearer's Protection Factor is calculated as: (ambient fibre concentration) / (in-facepiece fibre concentration). For high performance RPE tested in relatively "low" ambient fibre concentrations there is therefore the potential for the measured Protection Factors to be underestimated due to undercounting of dense ambient filters and over-counting sparse in-facepiece filters, i.e. the numerators and denominators respectively in the above calculation. If fibre densities on the ambient and in-facepiece sampling filters differ by more than about one order of magnitude counting errors due to the effects of fibre densities may be significant. Ideally, fibre densities on ambient and in-facepiece sampling filters should be equal.

For full details of the airborne asbestos fibre analysis technique and its limitations see MSDH 39/4, HSE (1995).

It should be stressed that there is currently no fully validated technique for assessing airborne asbestos fibre concentrations. That is, it is not possible to determine whether the fibre density on the sampling filter obtained is suitable for analysis until at least some hours after sampling has been completed.

5 DEVELOPMENT OF AMBIENT AND IN-FACEPIECE SAMPLING METHODOLOGIES

Workplace Protection Factor studies involve simultaneously measuring in-facepiece and ambient contaminant concentrations so that individual Protection Factors can be calculated as described above.

It was therefore necessary to develop suitable methodologies to take account of the anticipated individual Protection Factors likely to be achieved by a novel high performance device in the ambient asbestos fibre concentrations likely to be encountered.

5.1 Anticipated SE 400 Protection Factors

The SE 400 positive pressure demand filtering device is a novel device for which no existing workplace data are available. It was therefore necessary to consider the device's likely workplace performance so that relevant sampling criteria could be defined.

During revision of BS 4275 workplace data were not available for a number of devices, e.g. no data were available for Fresh Air Hose Breathing Apparatus. Assigned Protection Factors for such devices were based on identifying whether a device lacking

workplace data could be considered analogous to a device for which data were available. Fresh Air Hose Breathing Apparatus was deemed to be analogous to negative pressure full facepiece respirators and was assigned the APF of 40 assigned to that device.

It was considered that the closest analogous device to the SE 400 for which APF have been assigned are Full-facepiece Positive Pressure Demand Breathing Apparatus. The APF for this device is 2,000, BSI (1997).

The methodology developed for the SE 400 study should therefore permit individual Protection Factors of at least 2,000 to be quantified in likely ambient fibre concentrations.

5.2 Likely ambient asbestos fibre concentrations

During the Howie and Simpson (1991) and Howie et al (1996) workplace studies ambient asbestos fibre concentrations up to 1,000 fibres/ml of crocidolite and amosite were observed during the removal of dry asbestos-containing materials and when using power tools on asbestos-containing materials. The Health and Safety Executive (HSE) has since effectively prohibited dry removal of asbestos-containing materials and has restricted use of power tools. In situations where asbestos removal contractors comply with current HSE guidance on asbestos removal techniques ambient airborne asbestos fibre concentrations are generally below about 5 fibres/ml and below 1 fibre/ml in particularly amenable situations.

As only contractors complying with current HSE guidance on asbestos removal techniques were likely to permit access for carrying out a workplace protection factor study sampling methodologies had to be developed for both in-facepiece and ambient contaminant concentrations which would permit quantification of individual protection factors of 2,000 in ambient airborne fibre concentrations of 1-5 fibres/ml. The developed methodologies had to be validated before attempting to meet the study objective.

5.3 Methodology development

Methodology for the Workplace Protection Factor study on the SE 400 was developed and assessed in five main phases:

1) Development of ambient sampling methodologies;

2) Development of in-facepiece sampling methodologies;

3) Validation of above methodologies during a Preliminary Study;

4) Modification of the developed methodologies as necessary;

5) Application of modified methodologies during a Main Study

5.3.1 Development of ambient sampling techniques

Three major problems must be addressed when measuring ambient fibre concentrations during workplace protection factor studies during asbestos removal operations:

1) The ambient sampling head must not be flushed by exhaust air from the RPE;

2) Fibre density on the sampling filter should not exceed 400 fibres/mm^2;

3) Changing ambient sampling heads should neither cause the RPE wearer to modify his work pattern nor cause annoyance.

Ensuring the ambient sampling head is not flushed by exhaust air from the RPE

The exhaust from the RPE being tested is essentially clean air. If the clean exhaust air is permitted to flush over the ambient sampling head, the measured ambient concentrations may be lower than at locations not so affected.

The exhalation valve in the SE 400 full-facepiece effectively exhausts through about 360 degrees with some proportion of the exhaust air impinging on the wearer's chest and lapel area. To ensure that the ambient sampling is not affected by clean exhaust air the ambient sampling head was mounted on the facepiece clear of exhaust air.

Current standard asbestos sampling heads are too large and too heavy to mount on the facepiece without possibly affecting fit and/or comfort. Non-standard sampling heads therefore had to be used for measuring ambient fibre concentrations.

Small electrically conducting sampling heads c 9 mm diameter by c 10 mm long have been developed by this author for other studies - see Figure 3 which shows the standard 25 mm asbestos cowled sampling head and the open 7 mm miniature sampling heads.. These sampling heads are fitted with a 7 mm diameter sampling filter with air drawn though a 5.1 mm diameter area. The small sampling heads have been validated in side-by-side studies against standard asbestos sampling heads with flows of 2000 ml/min through standard heads and at 100 and 200 ml/min through the 7 mm sampling heads. These studies were carried out during work with Asbestos Insulating Board (AIB) containing amosite asbestos.

The validation tests demonstrated that the difference between standard 25 mm and 7 mm heads was not statistically significant. However, the small sampling heads appear to systematically undercount ambient concentrations measured using standard sampling heads by about 15% of figure. It is considered that such a systematic undercount, if

statistically significant, would be acceptable given the limited accuracy and repeatability of manual phase contrast optical microscopy and the necessity for mounting the ambient sampling heads on the RPE facepieces.

Ensuring fibre density on the sampling filter does not exceed 400 fibres/mm^2

To restrict sample density to 400 fibres/mm^2 on effective filter diameters of 5.1 mm the maximum total number of fibres collected should be limited to 8,171 fibres (400 x π x 2.55^2). Assuming a total respirator wear period of, say, 240 minutes, the maximum permissible sampling flow rate would be 34 ml/min, (8,171 fibres/240 min).

A number of publications have suggested that at low flow rates asbestos fibres can be drawn onto the sampling filter by a combination of electrostatic and diffusion effects, e.g., Beckett (1980). Minimum sample flow rates of 120 ml/min were therefore used during the Preliminary Study, i.e. within the range of flow rates for which validation data are available for the 7 mm sampling heads. At such flow rate the fibre density on the sampling filter would exceed 400 fibres/mm^2 in about 65 minutes in ambient concentrations of 5 fibres/ml. Ambient sampling should therefore be changed every 15 to 60 minutes.

Ensuring that changing ambient sampling heads during the work period neither causes the RPE wearer to modify his work pattern nor causes annoyance

Given the ambient sampling flow rate noted above, it was accepted that it would be necessary to change ambient sampling heads during each respirator wear period and to explain to test subjects why the ambient sample heads would need to be frequently changed.

Where possible, ambient sampling heads were to be changed only when it would not interfere with the test subject's activities.

Ambient sampling filters

All ambient sampling heads were fitted with 0.8 μm pore size Millipore AAWG gridded cellulose ester sampling filters. Note: gridded sampling filters are used as the grid marks simplify finding the correct field of focus during analysis. This is particularly important when analysing sampling filters with low fibre densities, such as may be found for in-mask samples.

5.3.2 Development of in-facepiece sampling techniques

Measurement of in-facepiece contaminant concentrations requires location of a suitable probe within the wearer's breathing zone. Such probes and connections must not interfere with the fit of the facepiece, permit additional inward contaminant leakage, cause discomfort to the wearer or otherwise affect the performance of the device under test.

Three main requirements must be met when carrying out in-facepiece sampling for RPE workplace protection factor studies:

1) A representative sample must be obtained of in-facepiece contaminant concentrations;

2) Fibre density on the in-facepiece sampling filter should be sufficient to permit accurate analysis;

3) In-facepiece sampling must not introduce an additional leakage path.

Ensuring that a representative sample is obtained of in-facepiece contaminant concentrations

It has been recognised in Europe since the mid-1980s that in-facepiece contaminant concentrations are not uniformly distributed. For example, Bostock (1988) commented **"**it was observed that tracer concentration within the facepiece was non-homogenous in that repositioning the probe could cause a large change in the recorded tracer concentration. With a face seal leakage of nominally 6.5% (PF = 15), calculated PF of between 6 and 100 were obtained dependent on the position of the probe and the site of the leakage path". Bostock reported the following probe position effects for a half-mask with a leak at the chin:

Probe position	Recorded leakage (%)
Reference point	**5.5**
At mouth	**5.4**
Midway	**2.2**
Flush with surface	**0.9**

From the above, measured leakage can vary by a factor of up to 6 depending on probe position. Only a probe at the mouth gave a measure within a factor of 2 of the reference point. Note that the SE 400 full-facepiece is fitted with a half-mask inner cup. Errors such as noted above could therefore have a significant effect on measured Protection Factors for such facepieces.

Myers and Allander (1988) commented on the Liu et al (1984) probe widely used in Workplace Protection Factor studies in the USA "a commonly used in-facepiece sampling procedure has been shown to provide unrepresentative sampling on full-facepieces". Myers & Hornung (1993) measured sampling bias with the Liu et al probe and reported the following sampling head biases:

Probe	Bias - range (%)	Bias - mean (%)

Shallow Liu probe c6 mm diameter inlet 12-19 mm from mouth	-65 to +4 -33 to +15	-41 -13

From the above, the shallow Liu probe the measurement of in-facepiece concentration ranged between 35 and 104% of the true concentration, i.e. the in-facepiece concentration could be underestimated by a factor of 3. Protection Factors measured with the Liu probe would therefore be overestimated by the same factor. The shallow Liu probe approximates Bostock's above probe position "flush with surface".

Bostock's studies led to the adoption of a 25 mm diameter sampling probe in touch with, or in close proximity to, the wearer's lips in all relevant RPE European (CEN) standards, e.g., EN 136, CEN (1989), and EN 149, CEN (1991).

Large diameter deep probes were used in the Howie and Simpson (1991) and Howie et al (1996) workplace studies. However, further experience has suggested that there may have been limitations with the probes used in these two studies as the probes were only about 15 mm in diameter and were constructed from electrically non-conducting materials.

The probe shown in Figure 4 was therefore developed for the SE 400 study. The probe is constructed from electrically conducting brass. The head of the probe is 31 mm diameter and is preferably located in light contact with the wearer's lips or within about 5 mm of the lips. Sampling takes place through 8 off 2 mm diameter holes around the circumference of the head. The shape of the rear of the probe was selected to minimise pressure effects generated by air flow upsetting the operation of the SE 400's demand valve. The rear of the probe body is threaded to fit into the filter holder of the 7 mm diameter sampling head used for ambient sampling.

Ensuring that fibre density on the in-facepiece sampling filter is sufficient to permit accurate analysis

The in-facepiece sampling probe uses the same 5.1 mm effective diameter filter as the ambient sampling head. For given airborne fibre concentration and sampling flow rates the small sampling area provide about a about a 20-fold greater density than given with conventional 25 mm diameter sampling heads and about a 3-fold higher fibre density than the 9.5 mm effective diameter sampling heads used in the Howie and Simpson (1991) and Howie et al (1996) studies.

To further increase fibre density, a series of tests were carried with available personal sampling pumps to determine the highest flow rate that could be reliably maintained through a 5.1 mm effective diameter filter. These tests indicated that the SKC *Standard Universal Flow Pump* could maintain about 600 ml/min through a 5.1 mm diameter area of 1.2 μm pore size Millipore RAWG gridded cellulose ester sampling filters.

SKC *Standard Universal Flow Pumps* were used for the Preliminary Study only as three new pumps failed due to the backpressure generated by the flow through the in-facepiece sampling head although the backpressure was within the 40 cm water gauge capacity claimed for the pumps.

Following further investigation, pumps were obtained from JD Services which were able to reliably maintain a flow rate of 800 ml/min through the sampling filters. These latter pumps were used for the Main Study.

During the Howie et al (1996) study it was recognised as unlikely that ambient fibre concentrations would be high enough to permit quantification of high protection factors if in-facepiece fibre densities were required to exceed 100 fibres/mm^2. It was therefore necessary to define an alternative in-facepiece fibre density which could be considered to be quantifiable.

Unused filters for sampling asbestos are permitted to have six apparent fibres in 200 graticule areas when mounted and counted using the standard analysis technique defined in MDHS 39/4, HSE (1995). Such apparent fibres are due to artefacts on the filter and are not actual fibres. Assuming that real fibres are randomly deposited on the sampling filter, the 95% upper Poisson distribution boundary count for 6 observed fibres would be 11.8 fibres. The limit of quantification was therefore considered to a be fibre density of 12 fibres per 200 graticule areas. That is, a fibre density of 7.6 fibres/mm^2.

If a respirator wear period of 180 minutes and a sampling flow rate of 800 ml/min is assumed, the in-facepiece sensitivity for a fibre density of 7.6 fibres/mm^2 on the sampling filter would be 0.0011 fibres/ml when using the JD Services pumps at 800 ml/min during the Main Study. That is, individual Protection Factors of 2,000 could be quantified in ambient concentrations of 2.2 fibres/ml. In practice, higher individual Protection Factors could be detected although less reliably quantified. For example, if 3 fibres per 200 graticule areas were counted on an in-facepiece filter for a test carried out in an ambient concentration of 2.2 fibres/ml, the nominal Protection Factor would be 8,000.

Any errors due to the observed fibre count being affected by filter artefacts would be to increase the apparent number of fibres observed and thus reduce the apparent Protection Factor. That is, any errors due to filter artefacts would be to reduce the calculated Protection Factor, i.e. the presence of any artefacts would err in favour of the wearer rather than in favour of the RPE device being evaluated.

Ensuring in-facepiece sampling does not introduce a source of inward leakage.

All tubing connectors through the facepiece to the in-facepiece sampling probe were sealed with a suitable flexible mastic.

All modified facepieces were evaluated on test subjects using a TSI ***Portacount Plus Respirator Fit Tester*** to demonstrate that a Fit Factor of at least 5,000 was achieved.

5.3.2 Development of in-facepiece sampling techniques

Three sets of Control samples were collected:

Filter Controls: unused filters removed from filter containers at random and analysed;

Sample Head Controls: filters fitted into in-facepiece sample heads and then removed and analysed without the analyst being aware of the filter origin;

Field Controls: filters fitted into in-facepiece sample heads which were then handled as normal samples but not used. Filters in the Field Control Heads were and removed and analysed without the analyst being aware of the filter origin.

The analyst routinely selected and analysed Filter Controls.

One Sample Head Control and one Field Control was taken each day.

6 STUDY PROTOCOL

The study protocol addresses a number of aspects such as a requirement that the study devices had been EC certificated, investigator training and certification, test subject training and supervision, the provision of quantitative fit testing, sample issue and recovery and sample analysis.

6.1 EC Certification

Prior to both the Preliminary and Main Workplace Protection Factor studies the SE 400 devices to be evaluated were tested and EC certificated - see Appendix l.

6.2 Investigator role, training and medical certification

Role of investigators

Investigators were responsible for supervising test subjects in the asbestos stripping enclosure, switching sampling equipment on and off as required and recovery of samples from used equipment.

The investigators were responsible for cleaning, servicing and testing SE 400 devices and sampling equipment.

Investigator training

All investigators had undergone training in asbestos decontamination procedures and use of RPE for work with asbestos.

Medical certification of investigators

All investigators had undergone the standard HSE approved medical examination and were certificated as asbestos workers.

6.3 Test subject training and supervision

In preparation of the revised BS 4275, BSI (1997) it was recognised that Workplace protection Factor studies could be carried using at least two main protocols: a stringent protocol defined by Guy (1985) and a protocol considered to be more representative of typical RPE usage in the UK.

Guy (1985) defined a Workplace Protection Factor study as "A measure of the protection provided in the workplace, under the conditions of that workplace, by a properly selected, fit tested and functioning respirator when correctly worn and used". In such studies, the test subjects are trained in all aspects of RPE wear and usage and are effectively supervised by the investigators on a one-to-one basis throughout the period of respirator wear.

It was considered by the BSI Committee which drafted the revised BS 4275 that such rigour was unlikely to be representative of UK workplaces. The BSI Committee therefore defined a study in which the test subjects are trained only in the use of the specific study device and where supervision is as low key as is conducive to ensuring that test subjects do not undertake unsafe activities. Such studies were defined as having followed an "As is" Protocol, BSI (1997).

The workplace studies of the SE 400 positive pressure demand filter device adopted the "as is" protocol defined by the BSI Committee. That is, test subjects were provided only with training in the specific characteristics of the SE 400 device and not in general RPE usage, i.e. to understand the importance of the audible and visual alarm signals.

The investigators did not interfere with the activities of the test subjects unless unsafe activities were observed, e.g. incorrect fit, displacement or removal of the facepiece in a contaminated area.

6.4 Quantitative fit testing and measurement of facial dimensions

It is a requirement of current HSE guidance that all asbestos workers carry out a quantitative fit test every time a new type of RPE is introduced or if there have been significant changes in the wearer's facial characteristics, e.g. after fitting new dentures, HSE (2000).

All test subjects underwent quantitative fit testing with the SE 400 using a TSI *Portacount Plus Respirator Fit Tester*. All test subjects were required to achieve a Fit Factor greater than 2,000 when tested in the power-off mode prior to participating in

the studies. During the fit tests subjects undertook a defined series of head movements - see Table 1.

For the purposes of the Fit Test the in-facepiece probe for the Workplace Protection Factor study was used. No sampling filter was fitted to the probe during fit tests.

The measured Fit Factors are therefore likely to be substantially lower than would generally have been obtained if the normal sampling point for Portacount testing had been used.

As noted above, the quantitative fit test also functioned as an assurance that modification of the facepiece to permit in-facepiece sampling had not degraded the protection provided.

Menton-nasal lengths, face depth and width and lip length were measured for all test subjects.

6.5 Provision and recovery of samples

Each subject was issued with his own SE 400 facepiece, breathing hose and fan unit. Ambient and in-facepiece samplers were pre-fitted onto the facepiece.

Sampling pumps were not switched on until the test subject had transited into the asbestos stripping enclosure. The sampling equipment was switched on by an investigator in the enclosure who also wore an SE 400 and the relevant protective clothing. Prior to test subjects leaving the asbestos stripping enclosure, the in-enclosure investigator switched off the sampling equipment.

The test subjects then underwent their normal decontamination procedures in the airlock entry to the stripping enclosure and transited to the Personal Decontamination Unit.

A second investigator, also wearing an SE 400, recovered the ambient samplers in the dirty end of the Personal Decontamination Unit. The test subjects then stripped off all clothing and entered the shower area where they thoroughly wetted their hair and body and cleaned the outside of the facepiece. After such preliminary decontamination, the facepiece was carefully removed to ensure that the in-facepiece filter head was not wetted and the facepiece, complete with the in-facepiece sampling head, was handed out to the investigator in the dirty end. The investigator recovered the in-facepiece sampling head for analysis.

After recovering all sampling heads, the second investigator then went through the decontamination procedure himself.

6.6 Sample analysis

Sample analysis was undertaken by an Accredited analytical laboratory which participated in the Regular Inter-laboratory Counting Exchange (RICE).

7 RESULTS AND DISCUSSION

Quantitative Fit Factors and Facial Dimensions for all workmen and investigators are shown in Table 1. The Table also indicates test subjects' smoking status.

Note that as the investigators were not working at the same rates as the workmen and were not in the same aerosol cloud as the workmen, the investigators' Protection Factors are therefore not included in analysis of 95^{th} percentile Protection Factors.

7.1 Preliminary Study

Five workmen participated in the Preliminary Study. All workmen wore the SE400 on standard belt, Part. No. WB1. Note: Padded Belt WB2S or Back pack BP1 were not available during the Preliminary Study.

The Preliminary Study was undertaken at one site.

Site 1 - Confined attic space with pipe insulation containing crocidolite, amosite and chrysotile. Asbestos removed four by workmen over period of three days. Contamination had to be removed from the eaves of the attic, so resulting in very awkward and constrained work spaces -Figures 5. Attic was dirty with non-fibrous dusts such as soot, sawdust and wood fibres.

7.1.1 Observations

1) No unsafe activities were observed.

2) One main filter was knocked off during work in a severely constrained space.

3) Use of an SE 400 respirator with a flat battery was observed one occasion. The Protection Factor for this wear period is not included in the data analysis below.

4) Problems due to water ingress into fan and communication units were observed.

5) All workmen found the SE 400 comfortable and expressed a preference for the SE 400 over the conventional powered respirator normally worn (Protector Safety).

6) All workmen were impressed with the Communication device as this substantially eased the problem of communicating with the Supervisor outside the enclosure.

7) Three workmen found that the in-facepiece sampling probe caused discomfort.

7.1.2 Observed Workplace Protection Factors

Measured ambient fibre concentrations, in-facepiece fibre concentrations and calculated Protection Factors are shown in Table 2.

From Table 2 fourteen valid Protection Factor results were obtained for the workmen test subjects. Protection Factors for the workmen ranged between 50 and >14,000 and for investigators ranged between 150 and >7,800. Of the fourteen valid workmen's Protection Factors only one was based on a quantifiable in-facepiece count: subject lV on Day 3 am, 15 fibres per 200 graticule areas. Only one further in-facepiece count exceeded the six counts per 200 graticule areas permitted for unused sampling filters: subject V on Day 2 pm, 7 fibres per 200 graticule areas. Five workmen's in-facepiece filters generated zero fibre counts. Protection Factors associated with zero in-facepiece counts are calculated on the basis of in-facepiece counts being less than 0.5 fibres.

Due to the presence of zero count results, it was necessary to analyse the Protection Factors using non-parametric analysis to determine the 95^{th} percentile. Rank-order analysis was used where the percentile associated with the i^{th} sample of n is given by:

$$\text{percentile} = 100\ (1- (i-0.33)/(n+0.33))$$

The fourteen workmen's rank-ordered Protection Factors from the Preliminary Study are listed in Table 3.

For fourteen results the 95^{th} percentile lies between the lowest and second lowest result, i.e. between 50 and 160.

This was a substantially lower Protection Factor than the figure of 2,000 anticipated.

Following receipt of the results of the Preliminary Study Safety Equipment Australia modified both SE 400 software and hardware.

From experience gained during the Preliminary Study it was recognised that the sampling methodology also needed to be modified.

7.2 Modifications arising from the Preliminary Study

7.2.1 Modifications to SE 400 device

Prior to carrying out the Main Study the SE 400 was modified in the light of experience during the Preliminary Study and at other sites.

Hardware modifications

The main filters during the Preliminary Study clipped into rubber bellows. To provide a more robust fitting, the rubber bellows were replaced with DIN threaded fittings. Figures 6 show the rubber bellows used in the SE400 unit and the DIN threaded units used in the SE 400AT unit.

Waterproofing of the fan units was improved.

A waterproof connector was provided for the communication unit. Figures 7 show the connectors used with the SE400 and SE400AT units.

Software modifications

The SE 400 tested in the Main Study was fitted with improved firmware which modifies how the fan responds to deep breathes and speech, so further reducing the risk of generating negative-pressure spikes in the facepiece during such activities.

The improved fan units used in the Main Study have been classified as SE400AT.

Safety Equipment Australia submitted the SE400AT units for EC testing and certification prior to the Main Study.

The Main Study was carried out only after EC Certification was completed.

7.2.2 Modifications to sampling methodology

As noted above the preliminary study revealed shortcomings of the sampling methodology:

unreliability of the SKC *Standard Universal Flow Pumps*;
obscuration of ambient sampling filters by non-fibrous particulates;
discomfort caused by the in-facepiece sampling probe.

***Unreliability of SKC** Standard Universal Flow Pumps*
As noted above, the SKC *Standard Universal Flow Pumps* were found unable to maintain the required 600 ml/min through the in-facepiece probes over the duration of two work periods per day. Three new *Standard Universal Flow Pumps* were expended during the Preliminary Study. Following extensive testing SKC *Standard Universal Flow Pumps* were replaced with JD Service pumps which had demonstrated the ability to reliably maintain a flow rate of 800 ml/min through the in-facepiece sampling heads.

Obscuration of ambient sampling filters by non-fibrous particulates
A number of the ambient samples were too heavily obscured with non-fibrous particulate matter to permit accurate analysis.

Previous experience had indicated that filters from conventional asbestos sampling heads could be severely obscured by non-fibrous particulates and that use of size-selecting cyclone samplers of the Higgins-Dewell BCIRA type could resolve this problem. It was also found that size-selected sampling heads generated higher measures of airborne fibre concentrations than conventional asbestos sampling heads in the high amosite fibre/high non-fibrous particulate concentrations observed during removal of

Amosite Insulation Board, (Howie - in print). That is, conventional asbestos sampling heads caused underestimation of actual airborne fibre concentrations.

Small size-selecting samplers currently in development for other work were therefore modified for use in the SE 400 Workplace Protection Factor study.

The size-selecting samplers were configured to give a nominal 50% "cut" at 8 μm Unit Density Spheres (UDS) when operated at a flow rate of 100 ml/min and 4 μm UDS when operated at 25 ml/min. Note that due to the presence of the size-selector in front of the sampling filter, it is unlikely that either electrostatic or diffusion effects could cause significant attraction between airborne fibres and the sampling filter. Substantially lower flow rates could therefore be used with size-selecting samplers than with conventional open heads.

The resulting lower flow rates permitted a single ambient sampler to be operated throughout a full respirator wear period of up to four hours in the likely ambient fibre concentrations, thus reducing the possibility of causing test subjects modifying their activities and reducing annoyance.

The modified size-selecting samplers were used in parallel with open 7 mm sampling heads to provide a direct comparison between size-selected and open sampling heads.

It was found that the JD Service pumps could reliably maintain 800 ml/min through the in-facepiece sampling head and also either 100 or 25 ml/min through both an open 7 mm
filter and a miniature size selecting sample head. That is, the JD Service pumps permitted one sampling pump to operate both the in-facepiece sampler and two ambient samplers. One sampling pump could therefore be dispensed with, thus lightening the load on the test subjects.

Discomfort caused by in-facepiece sampling probe

During the Preliminary Study the in-facepiece sampling probe was supported on a bracket mounted on the Demand Valve unit. In practice it was difficult to modify probe position to accommodate test subjects' individual requirements.

In the Main Study care was taken to match the in-facepiece sampling probe to individual wearers. This led to the in-facepiece probe being supported on the plastic face visor as this permitted matching to individual wearers.

Figure 8 shows the form of the in-facepiece sampling probe adopted for the Main Study. Note that for the purposes of the photograph the inner cup normally fitted to the facepiece has been removed. The inner cup was refitted to all facepieces during the Main Study. The Figure also shows the open and size selecting sampling heads fitted to an SE400AT facepiece.

7.3 Main study

Each respirator wearer wore one sampling pump connected to the in-mask sampling head and to two ambient sampling heads, one open head and one size selecting head.

Ambient sampling heads were operated at 105 ml/min in “low” ambient fibre concentrations and at 25 ml/min in “high” ambient fibre concentrations to maximise the fibre density on the sampling filter.

Only SE400AT devices as described above were used in the Main Study.

Five workmen participated in the Main Study, three of whom had participated in the Preliminary Study.

The workmen wore the SE400AT carried on either Standard Belt Part No. WB1, Padded Belt WB2S or Back pack BP1 depending on the nature of their task or site characteristics. An SE400 worn with the Back Pack is shown in Figure 1. Each workman selected the carrying device himself on a day-to-day basis.

7.3.1 Main Study sites

The Main Study was carried out four sites:

Site 2 - Low rise office building - Removal of amosite pipe insulation from under-floor areas and removal of potentially contaminated rubble. Movement of rubble generated very high work rates in the workmen.

Site 3 - High rise office tower building - Removal of screwed amosite ceiling tiles from toilet suites. Work space relatively constrained.

Site 4 - Bathroom in high-rise flats - Removal of amosite board from bathroom wall. Work space constrained.

Site 5 - Hot air heater - Removal of amosite insulated hot air central heating system. Work space constrained. Packaging and movement of approximately 400 kg of heavy and dense cast iron heat storage blocks generated high work rates.

Due to the restricted workspace at Sites 4 and 5 there was no supervising investigator inside the asbestos enclosure.

7.3.2 Observations

1) No unsafe activities were observed.

2) No loss of main filters was experienced although most of the work at all Sites involved high energy rates in constrained workplaces.

3) Due to the high workrates at Site 2 batteries went flat within about three hours when bagging and manhandling rubble. All subjects with flat batteries refitted a charged battery as soon as possible.

4) Problems due to water ingress into the fan unit and the Communication unit were still experienced but much less frequently than during the Preliminary Study.

5) No discomfort due to the in-facepiece sampling probe was reported.

6) The Padded Belt WB2S or Back pack BP1 were preferred by all subjects in situation where workspace was constrained. NB: all workplaces in the Main Study had adequate headroom as compared with the Preliminary Study where headroom was severely constrained.

7.3.3 Calculation of ambient airborne fibre concentrations

Ambient fibre concentrations as measured using size-selecting and open 7 mm sampling heads are shown in Appendix ll.

Analysis of the results indicates that there was no significant difference between the two sampler types at Site 2. Previous experience has demonstrated that there is no difference between size-selecting and open sampling heads in low ambient fibre concentrations such as observed at Site 2. The lack of difference between size-selecting and open sampling heads is therefore as expected. Analysis of results from Sites 3, 4 and 5 demonstrated that measured concentrations with the size-selecting samplers were statistically about 40% higher than with the open samplers, (r^2 = 0.94). That is, as demonstrated by previous experience using Higgins-Dewell cyclones and conventional open asbestos sampling heads.

Measures of ambient fibre concentrations, and thus Protection Factors, were therefore based on results from size-selecting samplers.

Measured ambient fibre concentrations, in-facepiece fibre concentrations and calculated Protection Factors are shown in Table 4 for Site 2, Table 5 for Sites 3, 4 and Table 6 for Site 5.

7.3.4 Workplace Protection Factors

From Tables 4-6 a total of 45 Protection Factors results were obtained for workmen test subjects: 26 at Site 2, 2 each at Sites 3 and 4 and 15 at Site 5. Six Protection Factors were obtained for the investigator. Protection Factors for the workmen ranged between 23 and >67,000 and between >15 and 6,400 for the investigator. The highest in-facepiece fibre count was 3.5 fibres/200 graticule areas, subject Vl at Site 2 on Day 2 pm. None of the in-facepiece fibre counts was quantifiable and all in-facepiece fibre counts were below the figure of 6 fibres per 200 graticule areas permitted for unused

sampling filters. Twenty-three of the workmen's in-facepiece filters generated zero fibre counts.

From Table 4 the highest ambient fibre concentration observed at Site 2 was 0.027 fibres/ml. The low ambient fibre concentrations at Site 2 results in apparently "low" Protection Factors even where zero in-facepiece fibres were observed. For example, on the afternoon of day 5 test subject l had zero fibres detected on his in-facepiece sampling filter and a calculated Protection Factor of >30 in an ambient concentration of <0.002 fibres/ml. From Table 6 the same test subject at Site 5 had zero fibres detected on his in-facepiece sampling filter on the morning of day 3 and on day 7. For these two wear periods the calculated Protection Factors were >2,400 and >10,000 in ambient concentrations of 0.14 and 0.74 fibres/ml respectively. That is, even where zero fibres have been detected on the in-facepiece sampling filter, low apparent Protection Factors can arise purely as a mathematical consequences of low ambient fibre concentrations. A low ambient fibre concentration of 0.029 f/ml was also observed for subject Vl at Site 5 on day 3 pm,

Distributions of in-facepiece counts for Site 2 and for Sites 3,4 and 5 are shown in Table 7.

From Table 7 there was no evidence of asbestos fibre leakage into SE400AT facepieces on 50% of wear periods. In addition, the distribution of in-facepiece counts appears to be simply the Poisson distribution of observations for a true count of zero. Non-zero in-facepiece counts may therefore not be indicative of actual inward leakage of asbestos fibres.

The very similar proportion of zero in-facepiece counts at Site 2 and Sites 3-5 suggests that the low calculated Protection Factors at Site 2 and at Site 5 for subject Vl on day 3 pm are a mathematical consequence of very low ambient fibre concentrations rather than an indication of poorer performance in low ambient concentrations. It is therefore considered that the Protection Factor results obtained for Site 2 and for subject Vl on day 3 pm at Site 5 should be excluded from further analysis, i.e. calculation of the 95th percentile should be based only on the Protection Factors observed at Sites 3, 4 and 5, less the above noted result for subject Vl at Site 5. As previously discussed, the presence of zero in-facepiece count results makes it necessary to use rank-order analysis to determine the 95th percentile Protection Factor. The seventeen valid workmen's Protection Factors observed at Sites 3, 4 and 5 are listed in rank-ordered form in Table 8.

For seventeen results the 95th percentile lies between the lowest and second lowest result, i.e. 2,600.

The SE400AT positive pressure demand powered filter device exhibited a 95th percentile Workplace Protection Factor of 2,600 when worn by contractor's employees during asbestos removal operations.

The above result suggests that the Assigned Protection Factor of 2,000 assigned to positive pressure demand breathing apparatus in BS 4275:1997 and HSE (1998) on the basis of professional judgement is unlikely to overestimate the performance of these devices.

8 CONCLUSIONS

There was no evidence of asbestos fibre leakage into SE400AT facepieces on 50% of wear periods.

The SE400AT positive pressure demand powered filter device exhibited a 95th percentile Workplace Protection Factor 2,600 when worn by contractor's employees during asbestos removal operations.

It is therefore concluded that an Assigned Protection Factor of 2,000 could validly be assigned to the SE400AT model evaluated in the Workplace Protection Factor study reported herein.

9 ACKNOWLEDGEMENTS

The author wishes to thank the stripping contractor who expended considerable effort to make suitable sites available for the study and Dion Froes who was responsible for sampling and subject supervision during the Main Study. Finally, but by no means least, the author wishes to thank the "strippers" whose ***always*** cheerful and interested co-operation made the study possible.

TABLE 1: PORTACOUNT FIT FACTORS, FACIAL DIMENSIONS AND SMOKING STATUS

Facial Dimensions (mm)

Activities / Facial Dimensions / Smoking status	Test Subject								
	Workmen							Investigators	
	I	II	III	IV	V	VI	VII	I-1	I-2
Fit Factors									
Sitting	16,200	17,800	52,800	50,000	70,100	28,700	7,590	6,840	19,700
Head side-side	25,600	1,700	60,200	88,100	26,000	20,400	2,060	16,500	22,600
Nodding	30,800	6,650	37,100	83,000	6,170	62,100	9,170	15,500	22,700
Talking	10,100	16,900	3,190	11,900	1,780	14,700	7,080	14,530	3,130
Sitting	21,600	28,700	94,900	73,000	51,000	57,500	11,100	24,400	19,100
Overall	17,900	13,900	12,900	31,400	6,110	26,900	7,350	9,400	5,120
Facial Dimensions									
Menton-nasal	120	116	117	118	117	116	129	118	131
Face width	143	141	105	136	138	119	121	128	125
Face depth	120	126	150/190	119	120	120	138	120	118
Lip length	55	54	46	53	48	48	51	47	49
Smoking status	Smoker	Smoker	Smoker	Smoker	Smoker	Smoker	Smoker	Non-smoker	Non-smoker

TABLE 2: SE 400 PRELIMINARY STUDY

Fibre count (fibres/graticule areas) - Concentration (fibres/ml)

Day Time	Data	Test subject						
		Workmen					Investigators	
		I	II	III	IV	V	I-1	I-2
	Ambient conc'n	-	-	2.0	-	too dense	1.1	1.0
1	**In-mask count**	-	-	0/200	-	In-mask filter	0/200	0/200
am	**In-mask conc'n**	-	-	<0.0001	-	damaged	<0.00014	<0.0005
	PF	-	-	>20,000	-	-	>7,800	>1,100
	Ambient conc'n	2.0	0.24	-	too dense	1.6	0.56	-
1	**In-mask count**	Respirator	0/200	-	-	Battery	0/200	-
pm	**In-mask conc'n**	filter loss	<0.000073	-	-	failure	<0.000073	-
	PF	-	>3,300	-	-	[310]	>7,600	-
	Ambient conc'n	0.2	0.11	-	0.073	1.1	0.07	-
2	**In-mask count**	In-mask filter	1/200	-	0/200	0/200	2/200	-
am	**In-mask conc'n**	spoiled	0.00015	-	<0.000075	<0.000079	0.00035	-
	PF	X	730	-	>970	>14,000	570	-
	Ambient conc'n	-	0.32	-	0.24	0.20	0.19	
2	**In-mask count**	-	5/200	-	1/200	7/200	1/200	-
pm	**In-mask conc'n**	-	0.00093	-	0.00026	0.0013	0.00026	-
	PF	-	350	-	920	160	720	-
	Ambient conc'n	0.24	-	-	0.11	0.16	0.012	
3	**In-mask count**	2/200	-	-	15/200	4/200	0/200	-
am	**In-mask conc'n**	0.00029	-	-	0.0022	0.00058	<0.000077	-
	PF	>800	-	-	50	280	>150	-
	Ambient conc'n	0.28	-	-	0.069	0.03		
3	**In-mask count**	0/200	-	-	1/200	0/200	-	-
pm	**In-mask conc'n**	<0.00012	-	-	0.00024	<0.00012	-	-
	PF	>2,300	-	-	290	>260	-	-

TABLE 3: Workmen's rank-ordered Protection Factors from Preliminary Study

50**
160*
>260
280
290
350
730
>800
920
>970
>2,300
> 3,300
>14,000
>20,000

Notes: * in-facepiece count > 6 fibres/200 graticule areas
** quantifiable in-facepiece count

TABLE 4: SE400AT MAIN STUDY - SITE 2

Fibre count (fibres/graticule areas) - Concentration (fibres/ml)

Day Time	Data	Test subject Workmen I	II	IV	VI	VII	Investigator I-3
	Ambient conc'n	0.0033	-	0.0046	0.002	0.0014	
1	**In-mask count**	0/200	-	0.5/200	0/200	0/200	artefacts on
pm	**In-mask conc'n**	<0.000034	-	0.000052	<0.000051	<0.000038	in-mask filter
	PF	>100	-	88	>38	>37	
	Ambient conc'n	0.018	-	0.0044	0.021	0.027	0.013
2	**In-mask count**	1/200	-	1/200	0.5/200	1/200	0/200
am	**In-mask conc'n**	0.00015	-	0.00016	0.000082	0.00014	<0.00011
	PF	120	-	27	250	190	>120
	Ambient conc'n	0.011	-	0.022	0.027	0.027	0.0023
2	**In-mask count**	1/200	-	0/200	3.5/200	1.5/200	0/200
pm	**In-mask conc'n**	0.00021	-	<00010	0.00070	0.00028	<0.000015
	PF	57		>210	38	94	>15
	Ambient conc'n	0.008	0.0077	0.0025	-	0.0019	-
4	**In-mask count**	0/200	1/200	0/200	in-mask filter	0/200	-
am	**In-mask conc'n**	<0.000075	0.00017	<0.000080	did not claer	<0.000064	-
	PF	>110	46	>30	-	>30	-
	Ambient conc'n	0.0066	0.0039	0.0016	0.0070	0.0029	0.0056
4	**In-mask count**	1/200	1/200	0/200	0/200	1/200	1/200
pm	**In-mask conc'n**	0.00013	0.00017	<0.000072	<0.000067	0.00013	0.00016
	PF	50	23	>23	>110	23	34
	Ambient conc'n	0.0058	-	-	-	-	
5	**In-mask count**	0/200	-	-	-	-	damaged in-
am	**In-mask conc'n**	<0.000060	-	-	-	-	mask filter
	PF	>100	-	-	-	-	
	Ambient conc'n	<0.002	0.018	0.0093	-	0.0086	-
5	**In-mask count**	0/200	0/200	0/200	-	0/200	-
pm	**In-mask conc'n**	<0.000070	<0.000070	<0.000073	-	<0.000067	-
	PF	>30	>260	>130	-	>130	-

TABLE 5: SE400AT MAIN STUDY - SITES 3 AND 4

Fibre count (fibres/graticule areas) - Concentration (fibres/ml)

Day Site	Data	Test subject Workmen I	II	IV	VI	VII	Investigator I-3
	Ambient conc'n	-	5.8	-	5.1	-	-
5	**In-mask count**	-	0/200	-	1/200	-	-
Site 3	**In-mask conc'n**	-	<0.000098	-	0.00020	-	-
	PF	-	>59,000	-	3,500	-	-
	Ambient conc'n	-	2.1	-	4.4	-	-
6	**In-mask count**	-	1.5/200	-	0/200	-	-
Site 4	**In-mask conc'n**	-	0.00020	-	<0.000065	-	-
	PF	-	>11,000	-	>67,000	-	-

TABLE 6: SE400AT MAIN STUDY - SITE 5

Fibre count (fibres/graticule areas) - Concentration (fibres/ml)

Day Time	Sample	Test subject					
		Workmen					Investigator
		I	II	IV	VI	VII	I-3
	Ambient conc'n	0.16	0.41	0.18	0.54	-	0.19
3	**In-mask count**	0/200	0.5/200	0/200	0/200	-	1/200
am	**In-mask conc'n**	<0.000055	0.000056	<0.000047	<0.000056	-	0.00012
	PF	>2,900	7,400	>3,800	>9,600	-	6,400
	Ambient conc'n	-	0.46	0.52	0.029	-	0.21
3	**In-mask count**	in-mask filter	0/200	1/200	0/200	-	2/200
pm	**In-mask conc'n**	artefacts	<0.000052	0.00012	<0.000044	-	0.00029
	PF	-	>8,800	4,300	>660	-	724
	Ambient conc'n	0.74	0.74	0.74	1.5	-	
7	**In-mask count**	0/200	1/200	2/200	2/200	-	damaged
	In-mask conc'n	<0.000073	0.00015	0.00029	0.00029	-	in-mask filter
	PF	>10,000	5,100	2,600	5,100	-	
	Ambient conc'n	0.88	0.88	-	1.6	-	1.6
8	**In-mask count**	2/200	0/200	damaged	0/200	-	1/200
	In-mask conc'n	0.00034	<0.000086	in-mask filter	<0.000078	-	0.00028
	PF	2,600	>10,000	-	>20,000	-	6,000

TABLE 7: MAIN STUDY - DISTRIBUTION OF IN-FACEPIECE FIBRE COUNTS

In-facepiece counts	Site 2 (n = 26)			Sites 3, 4 and 5 (n = 18)		
	No of observations	%	% cumulative	No of observations	%	% cumulative
0	14	54	54	9	50	50
0.5 - 1	10	38	92	4	22	72
1.5 - 2	1	4	96	5	33	100
2.5 - 3.5	1	4	100	0	0	-

TABLE 8: Rank-ordered Protection Factors from Main Study Sites 3, 4 and 5

2,600
2,600
>2,900
3,500
>3,800
4,300
5,100
5,100
7,400
>8,800
>9,600
>10,000
>10,000
>11,000
>20,000
>59,000
>67,000

FIGURE 1: Sea 400 Positive Pressure Demand Filter Device worn on Back Pack BP1

FIGURE 2: SEA Communication Device SE-Talk S1

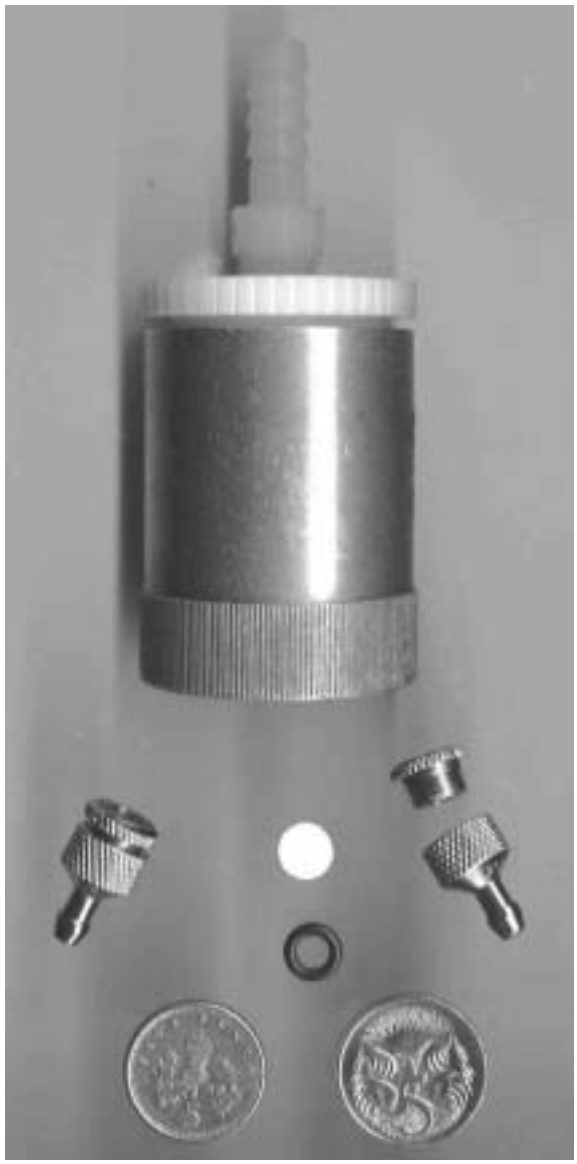

FIGURE 3: Ambient Fibre Sampling Devices - Standard Asbestos Sampling Head and Miniature 7 mm Sampling Head. Shown with UK 5p and Australian 5 cent coins

FIGURE 4: In-mask sampling probe. Shown with UK 5p and Australian 5 cent coins

FIGURE 5a: Preliminary Site – external view

FIGURE 5b: Preliminary site – subject working in eaves of attic space

FIGURE 6a: SE200 rubber bellows filter holders

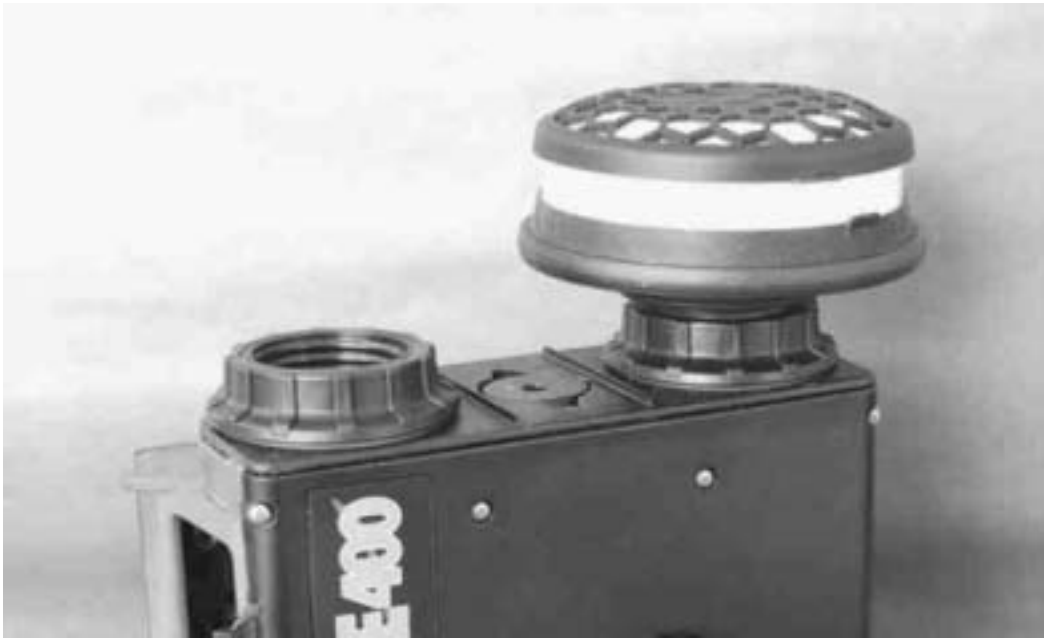

FIGURE 6b: SE400AT DIN-threaded filter holders

FIGURE 7a: SE400 communication device connector

FIGURE 7b: SE400AT communication device connector

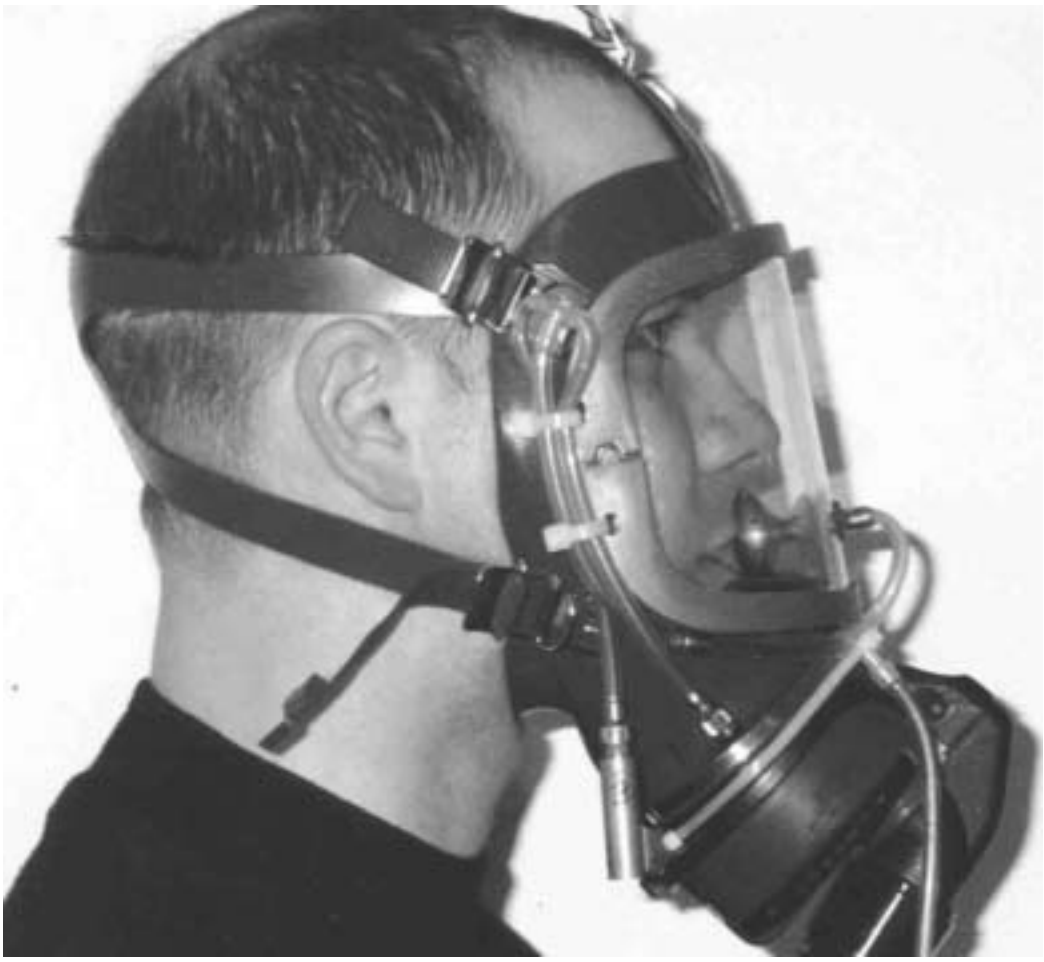

FIGURE 8: Open and size selecting ambient sampling devices fitted on SE400 facepiece. In-Mask probe and connection through facepiece visor is also shown. Note: inner-cup removed for purpose of photograph only.

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APPENDIX l

EC Certification and component part numbers

	Preliminary Study	**Main Study**
EC-Type Certification Certificate:	No. 656	No. 656 Amended
Fan Unit:	SE400	SE400AT
Full-facepiece	FS-DV2 silicone	FS-DV2 silicone
Breathing Hose:	H2	H2
Carrying device:	Standard belt WB1	Standard belt WB1 Padded belt WB2S Back pack BP1
Battery:	B1	B1
Battery charger:	BC1	BC1
Communication Device	SE-Talk S1	SE-Talk S1A
Particle Filters:	P4SL	P4SL
Filter holder:	N/A	280
Pre-filter:	221	221
Pre-filter holder:	PFH-SEA	PFH-SEA

APPENDIX ll

TABLE All - 1: COMPARISON OF SIZE-SELECTING AND OPEN SAMPLERS - SITE 2

Ambient Fibre Concentration (fibres/ml)

Day Time	Sampler	Test subject Workmen l	ll	lV	Vl	Vll	Investigator I-3
1 pm	Size-selecting	0.0033	-	0.0046	0.002	0.0014	0.0029
	Open	0.0025	-	X	0.002	0.004	0.0028
2 am	Size-selecting	0.018	-	0.0044	0.021	0.027	0.013
	Open	0.0081	-	0.00063	0.0076	0.0054	0.0065
2 pm	Size-selecting	0.011	-	0.022	0.027	0.027	0.0023
	Open	0.014	-	X	X	0.015	0.018
4 am	Size-selecting	0.008	0.0077	0.0025	-	0.0019	-
	Open	X	0.0013	0.0031	-	0.0019	-
4 am	Size-selecting	0.0066	0.0039	0.0016	0.0070	0.0029	0.0056
	Open	0.0026	X	X	0.0055	0.0048	0.0087
5 am	Size-selecting	0.0058	-	-	-	-	-
	Open	0.012	-	-	-	-	-
5 pm	Size-selecting	<0.002	0.018	0.0093	-	0.0086	-
	Open	<0.002	0.0068	0.0035	-	0.0032	-

Note: X filter(s) too dirty to count

TABLE All - 2: COMPARISON OF SIZE-SELECTING AND OPEN SAMPLERS - SITES 3, 4 and 5

Ambient Fibre Concentration (fibres/ml)

Day - Time Site	Sampler	Test subject Workmen I	II	IV	VI	VII	Investigator I-3
3 am Site 5	Size-selecting	0.16	0.41	damaged	0.54	-	0.19
	Open	0.058	0.26	0.18	0.26		0.23
3 pm Site 5	Size-selecting	-	0.46	0.52	-	-	0.21
	Open	-	0.45	0.21	-		0.21
5 Site 3	Size-selecting	-	5.8	-	5.1	-	-
	Open	-	2.8	-	3.5	-	-
6 Site 4	Size-selecting	-	2.1	-	4.4	-	-
	Open	-	1.5	-	2.9	-	-
7 Site 5	Size-selecting	0.74	0.74	0.74	1.5	-	
	Open	0.79	0.79	0.79	1.7		
8 Site 5	Size-selecting	0.88	0.88	0.83	1.6	-	1.6
	Open	0.72	0.72	0.67	1.4		1.7