

Performance of an Airfed Loose-fitting Helmet and Visor Respiratory Protective Device Worn during a Simulated Printing Works Activity

Shirley Frost¹ and Rhiannon Mogridge²

1 – Health and Safety Laboratory, Harpur Hill, Buxton SK17 9JN, UK
E-mail: shirley.frost@hsl.gov.uk

2 – Health and Safety Laboratory, Harpur Hill, Buxton SK17 9JN, UK

ABSTRACT

The type of airfed respiratory protective device used in this study has an assigned protection factor (APF) of 20 in the United Kingdom. When this value was set, no suitable data was available on the actual performance of this type of device in the workplace. Measurements were taken in order to establish how well this value reflects the actual performance of the device when worn during a simulated workplace activity. The work activity was light, requiring the volunteers to carry out simple cleaning of mixing bowls, spatulas and workbench using an organic solvent (1-methoxy-2-propanol). The purpose of the respiratory protective device was to provide protection from inhalation of the solvent vapour. The vapour concentrations inside and outside of the facepiece were measured at one second intervals using two separate portable Photoionisation Detection Units with datalogging capability.

Processing of *all* the data collected from *all* of the 15 test runs gave an overall 5th percentile simulated workplace protection factor of 232, well in excess of the assigned protection factor. During each of the 15 individual test runs the device provided a good level of protection for the 11 volunteers; all 5th percentile simulated workplace protection factors were well in excess of the assigned protection factor. This was to be expected as the wearer and the operation of the respiratory protective device were not under excessive or even moderate strain and there was no poor practice in the use of the equipment.

Under these conditions, this type of device is capable of providing a level of protection well in excess of that indicated by the APF of 20.

Keywords: simulated workplace protection factor, assigned protection factor, airfed respiratory protective device, airline respiratory protective device, light work activity.

INTRODUCTION

The assigned protection factor (APF) for a respiratory protective device (RPD) is a guide to the level of protection which the wearer can expect that device to provide when used in a workplace, if it is used according to the manufacturer's instruction. Although APFs are assigned to devices on the basis of their performance in workplace tests and expert opinion, the value given to the APF is generally lower than that obtained from laboratory certification tests. This lower value allows for the other factors which may come into play within an actual workplace situation. The extent of protection provided by a RPD may differ from one wearing to another, and it may also vary throughout each individual occasion of wear. Factors that affect the Protection Factor (PF) include:

- The class and condition of the device being worn

- The suitability of the device for the working conditions
- The suitability of the device for the wearer
- Work related factors
- How closely use of the device adheres to the manufacturer's instructions

Taking measurements within an actual workplace situation can make the best estimates of Workplace Protection Factor (WPF). The WPF is calculated from simultaneous measurements of concentrations of airborne substances both inside and just outside the RPD, during a workplace activity. From the distribution of results, an indication of the validity of APF values can be assessed. The expectation is for the observed 5th percentile WPFs to approximate to the APF for the device (as defined in EN 529:2005).

In practice it is difficult to take useful measurements within an actual workplace (Bolsover, Rajan and Vaughan: 2005). In order to comply with the law, concentrations of harmful substances within the workplace should be kept as low as is reasonably practical by engineering controls, other than RPD. Consequently, concentrations within the facepiece of the RPD should be much lower as the RPD will further reduce the in-facepiece concentration. Therefore, a measuring technique with a low detection limit and appropriate specificity is required, for which suitable equipment may not always be available.

A RPD is not normally considered necessary in printing industry work. However, a laboratory study was planned to assess the effectiveness of protective gloves which operators would normally wear when carrying out certain activities in the printing industry workplace (Roff M: 2006). In order to ensure that biological monitoring data represents the exposure via a dermal route through the gloves, RPD was required to significantly reduce the possibility of inhalation of solvent vapour contributing to the test results. This afforded an opportunity to assess the protection provided by the chosen RPD during this simulated workplace activity. At the time that the APF for this type of device was set, no suitable data was available on its performance in the workplace.

METHODS AND PROCEDURES

Respiratory protective device (RPD)

The RPD selected for use was a loose-fitting airfed helmet (airline RPD); the Protector Tornado[®] T-5 polycarbonate visor, helmet and hose, manufactured by Scott International Ltd. This required breathable compressed air which was supplied through a Protector Tornado[®] T-A-line Airline Belt Unit. The complete kit was purchased new for this work. This device is classified as LDH2 (light duty construction compressed air line breathing apparatus incorporating a helmet or a hood) according to the European Standard (prEN 1835,1999). This means that in the UK this device is considered to have an APF of 20. Figure 1 shows the device being worn by a test subject.

The RPD manufacturer's instructions do not include any restrictions of wearer suitability; therefore individual wearer characteristics should not critically affect its performance. The instructions do state that the RPD should be correctly fitted.

Clean air was supplied from the laboratory breathable air compressor, via a compressed air supply tube which connected into the belt regulator unit. This fed breathable air through a hose, routed via the wearer's back, into the visor-helmet. The hose terminated above the visor, such that clean air was supplied directly into the wearer's breathing zone. Unused and exhaled air could escape the device around the edges of the visor via the loose fitting face seal as well as through the exhalation valve, which is located beneath the chin.

The belt regulator unit is fitted with a low flow warning whistle and was operated using the minimum compressed air supply pressure to just prevent activation of this alarm. This was measured as approximately 3.6 bar, which supplied a flow rate of approximately 190 l min⁻¹. The manufacturer's instructions give the minimum flow rate as 140 l min⁻¹.



Figure 1. RPD as worn by a volunteer test subject.

Work Activity

In the printing industry, operators are required to clean ink from mixing bowls, spatulas and workbenches after use using an appropriate solvent. A workstation was set-up within a test chamber at the Health and Safety Laboratory using equipment similar to that used within the UK printing industry. Volunteers were shown a short video of the workplace activity and asked to repeat this process inside the fan-ventilated 10m³ test chamber. Several different solvents are used within the industry; the solvent selected for this study was 1-methoxy-2-propanol, because of its ease of detection and relatively low toxicity.

Measurement Method

Portable photoionisation detectors (PID's; the MultiRAE Plus manufactured by Rae Systems Inc.) were used to detect and record the solvent vapour concentration. Two units were used in order to simultaneously record the in-visor and ambient concentrations of the solvent vapour. The units were mounted on the RPD belt and connected to the sampling zone via identical lengths of tubing terminating in spherical sample probes (the 'ball' sample probe described in BS EN 12942: 1999). One was positioned just outside of the RPD visor (but away from the draught of clean air being expelled from the RPD) and the other within the visor, just in front of the mouth and nose of the wearer. Figure 1 shows the device being worn by a test subject. The PID units have internal pumps that operate at approximately 250

ml min⁻¹. The PID's recorded information once every second, which was downloaded onto a computer. The large amount of data generated allows for calculation of the 5th percentile, with high resolution achievable.

The PID units were zeroed against clean breathable air and calibrated, using a calibration gas, prior to each test run. After donning, the RPD was worn for a few minutes before the work activity began. Stable recorded in-facepiece vapour concentration measurement during this period was taken as the "subject zero" and subtracted from each in-facepiece measurement for that test run. The "subject zero" averaged 0.24ppm with a standard deviation of 0.37ppm.

Procedures

A total of 15 separate test runs were carried out using 11 different volunteers. One of the volunteers was female and was the test subject for two of the test runs. The remaining ten volunteers were male. Volunteers ranged in age from 20 to 60 years. None of the volunteers were unusually large or small in stature. Any significant observations, which might affect the suitability of fit of the RPD for the wearer, were recorded. The PID units were calibrated before each test run and, in order to synchronise the measurements, the PID units were briefly exposed to solvent both before and after each test run.

The initial test run (PInk 1) was shorter than the others as the volunteer only carried out one mixing and cleaning process. Subsequent tests involved volunteers repeating the process two or three times resulting in approximately 30 minutes of continuous work with the solvent. All test runs were considered valid and were included in the calculation of the overall 5th percentile SWPF.

RESULTS

Initial observations

Different volunteers used different working techniques and widely varying amounts of solvent, leading to differing levels of chamber solvent vapour concentration (challenge concentration). Peaks in the challenge concentration were observed when "cleaning up" after cleaning the ink bowl, specifically whenever the table was wiped down. The loosefitting RPD face seal did not fit some of the subjects closely due to their face shape or size, or the presence of facial hair and/or spectacles. However, the RPD was worn correctly (according to manufacturer's instruction) for the entire time that the test subject spent within the chamber.

In most cases, cleaning the ink bowl took about ten minutes, and therefore it was inked and cleaned several times during the course of the test in order to give an exposure time similar to that experienced by workers in industry (a total exposure time of around 30 minutes was typical). Repetitive peaks in the challenge concentration in several of the tests demonstrated this well. A graph of solvent vapour concentrations against time for a representative test run is shown in Figure 2. The first use of the solvent occurred just before 600 seconds, resulting in a sudden increase in challenge concentration. It can be seen from the raw data graph in Figure 2 that the in-facepiece concentration of solvent vapour was generally very low compared to the challenge concentration. This would seem to indicate that the RPD was providing a high level of protection.

Detection Limit effects

Figure 3 shows challenge concentration and protection factors calculated from raw data against time for a representative test run. For the early portion of each test (up to $t = 500$ s) where the challenge concentration was low, the protection factors calculated for individual data pairs were either very low or very high. As the challenge concentration increased with use of the solvent (from $t = 500$ s to $t = 850$ s) the protection factor continued to vary but not as widely. As the solvent concentration increased further, the protection factor became much more stable, although there were periods where it was apparently infinite.

These effects have been discussed in detail by Vaughan and Bailey (2003), and Vaughan and Rajan (2005). They can be described as follows:

$$PF = \frac{C}{I}, \quad \text{where } PF \text{ is the protection factor, } C \text{ is the challenge concentration} \\ \text{and } I \text{ the in-facepiece concentration}$$

Every measurement technique has a *detection limit* (DL), which can be defined as the lower limit point at which we can definitely say a substance is present when using that measurement technique. This is largely dependent upon the sensitivity and resolution of the instrumentation system used. If the actual signal and reading are very small and comparable in magnitude to the background “noise” of the measuring system, a slight change in concentration may be either not registered or indicated by a relatively large change in the instrument reading. These changes can have a significant effect on the calculated protection factor. From the equation above, it can be seen that, when C is low, changing the in-facepiece concentration I by a small amount, when it is already small, can change the protection factor significantly. As C increases, the extent of inward leakage (and hence I) will increase making the measurement of I more reliable and greater certainty can therefore be attached to the calculated value of PF .

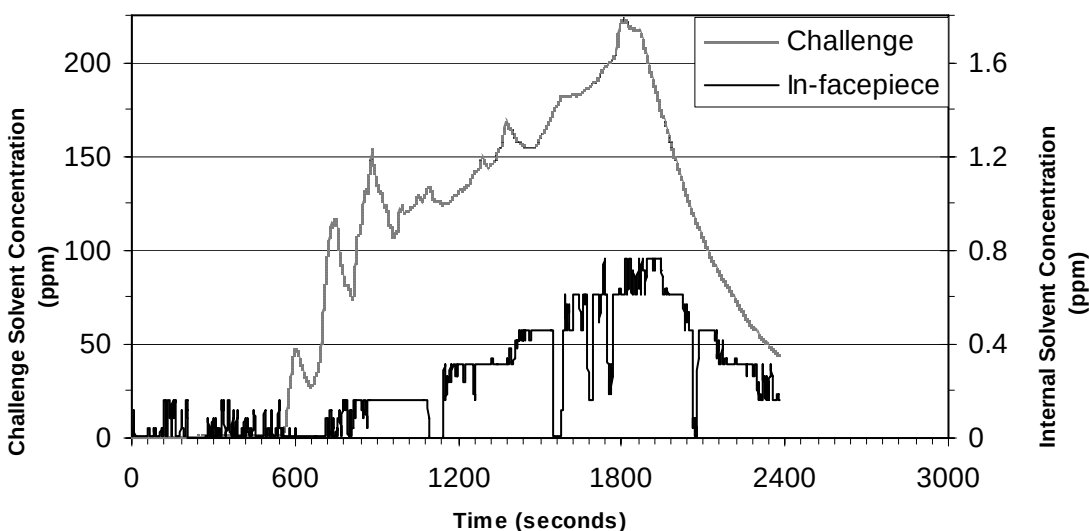


Figure 2. Measured in-facepiece and challenge solvent vapour concentrations for a single test run.

The DL is usually taken as 3 x the standard deviation of a stable measurement (Royal Society of Chemistry, 1987). The initial part of each test, where the challenge concentration is low, was used to calculate the standard deviation of the in-facepiece concentration. Examination of the data gave the median of these standard deviations as 0.04ppm, and therefore the DL of our measurement technique was calculated to be 0.12ppm.

In order to apply a stringent criterion, a worst-case scenario was assumed. Any in-facepiece concentration measurements less than the DL were taken to be at the DL for the purpose of calculating the protection factor. This causes the protection factor calculated from the substituted values to be biased low. As the challenge concentration increases sufficiently, readings less than the DL become less common, since there will be a reliably detectable inward leakage. Once the challenge concentration is

greater than some critical concentration, the problems associated with these biased readings will disappear and the calculated protection factor becomes more stable.

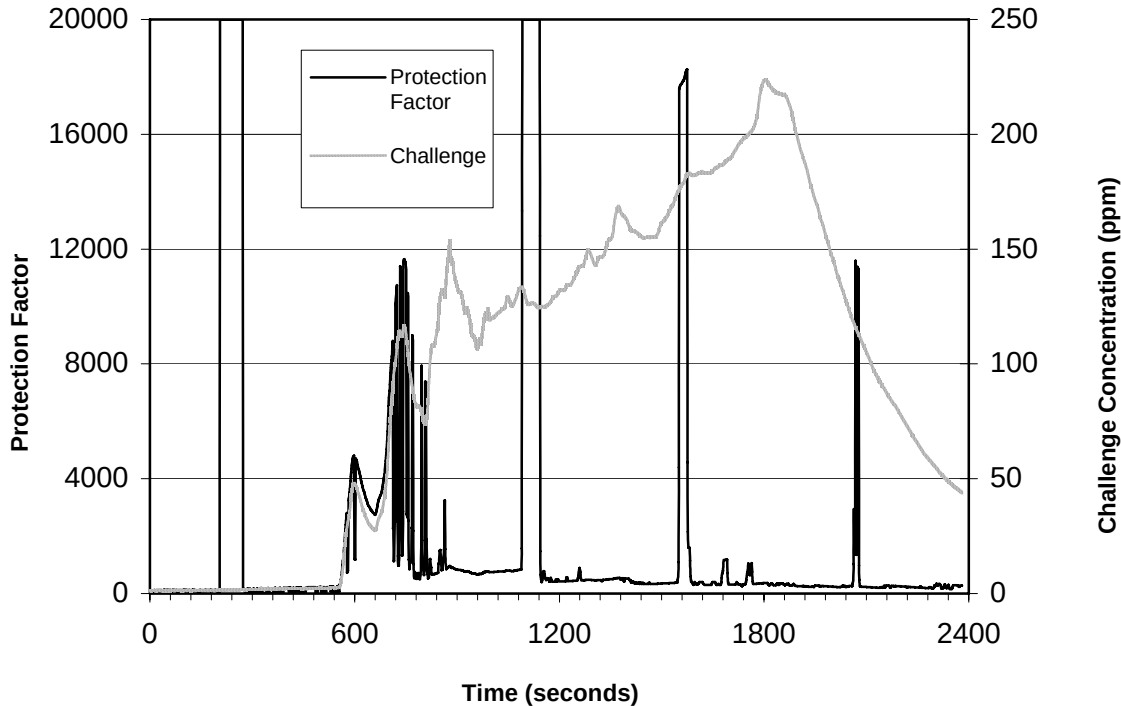


Figure 3. Challenge concentration and protection factor against time for a single test run.

Processing of data

(Note: Pairs of data points which have had the DL substituted for the in-facepiece concentration will be referred to as “DL data pairs”; those data pairs where the in-facepiece concentration is above the DL will be referred to as “non-DL data pairs”.)

There is, therefore, an argument for rejecting data pairs where both the in-facepiece concentration is less than the DL *and* the challenge concentration is less than this critical concentration (C_c), which we shall define as:

$$C_c = PF \times 10 \times DL$$

Where PF is the actual protection factor. The multiplier 10 is included to ensure that the in-facepiece concentration is well above the DL (Vaughan and Bailey: 2003).

This approach poses a problem, however, since the critical concentration is not known until the actual protection factor is known, and vice versa. Therefore, a value of the protection factor is estimated, and an iterative process used to determine the actual protection factor demonstrated by the data. This estimated protection factor will be referred to as the *assumed protection factor*, PF_a . The iterative process is terminated when one of the following cases occurs:

Case 1 – At least 100 data pairs remain and none of the in-facepiece measurements are below the DL for the measuring technique.

Case 2 – At least 100 data pairs remain and the assumed protection factor exceeds the calculated 5th percentile SWPF.

Case 3 – Only 100 data pairs remain.

In all cases 100 data pairs are used as a cut-off in order to ensure a resolution of at least 1% on the calculation of the 5th percentile.

There are additional factors that must be taken into consideration. Devices which exhibit a very high SWPF, such as the one used in these tests, require a very high challenge concentration before meaningful measurements of the SWPF can be made. If the challenge concentration is not high enough, then Case 3 will apply. In these circumstances, an actual value for the PF cannot be calculated, but a minimum value (i.e. a value which the PF cannot be lower than) can be estimated.

The easiest way to perform this procedure by hand is to use a graphical method, and plot the assumed PF against the calculated 5th percentile SWPF (equivalent to the assigned protection factor, APF). The point where these two are equal (where the 1:1 line intersects the plotted calculated PF line) gives the actual 5th percentile SWPF of the data.

Figure 4 shows an example of this. The graph is for all the data pairs collected. The initial rise in the calculated 5th percentile SWPF is due to the removal of data pairs with a low challenge concentration, which give a low protection factor due to the detection limit being imposed upon the in-facepiece concentration reading. The drop in the calculated 5th percentile SWPF after the “hump” is due to the elimination of DL data pairs with a reasonably high challenge concentration. Because the detection limit is the lowest possible in-facepiece value, these DL data pairs give a higher protection factor than the average of non-DL data pairs. Thus, removing them reduces the calculated 5th percentile SWPF somewhat. This is a case 2 example; the 1:1 line crosses the 5th percentile SWPF line before it levels off (before all the detection limit data pairs are eliminated).

Performing this iterative procedure manually, even in a spreadsheet programme, is a tedious and time-consuming process, and therefore a short spreadsheet macro program was written. This program returns the median and 5th percentile values of the SWPF, as well as information about each step of the iterative process.

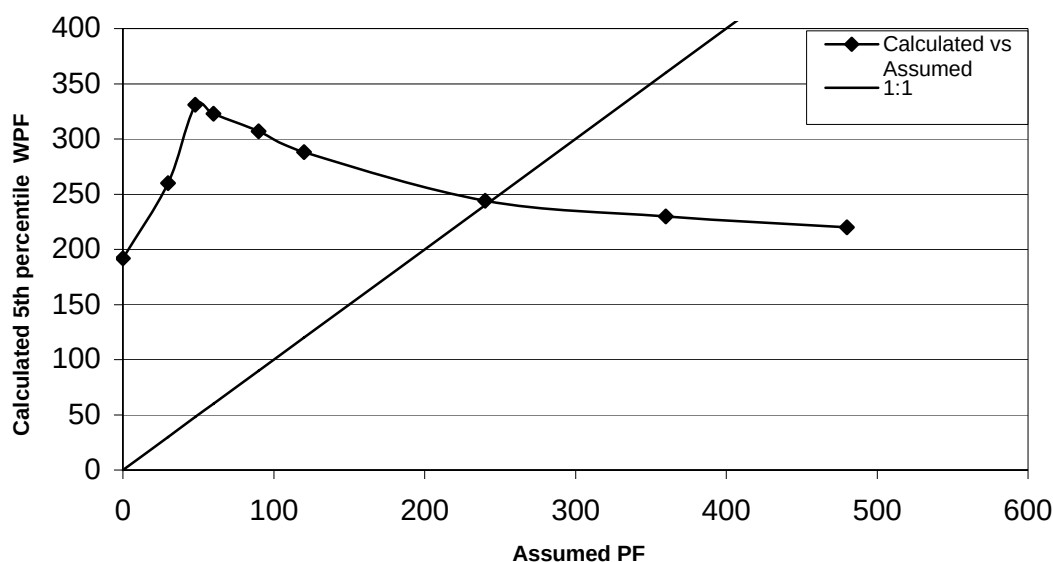


Figure 4. Calculated 5th percentile SWPF against Assumed PF for all data.

Processed Results

Using all available data from all 15 test runs together gave SWPFs for the RPD of 1005 and 232 for median and 5th percentile, respectively (the percentage of all the collected data pairs which the calculation process considered valid was 33%). The calculated 5th percentile SWPF is significantly higher than the APF for the device (BS EN 529: 2005, HSG 53; 2005), despite operating it at the lowest airflow possible without triggering the low-flow alarm. Column 2 of table 1 shows the mean protection factor for each test run calculated from the mean in-facepiece and mean challenge concentrations. It is not possible to derive a 5th percentile SWPF from these 15 averaged test results, with any confidence. With only 15 test results, only low resolution is achievable; extremes of protection given by the RPD are hidden within such averaged measurements.

Calculated and assumed protection factors for each test run are shown in Table I, along with additional data about why the iterative process was terminated (i.e. which of the above cases it belongs to). A large proportion of the data pairs had an in-facepiece concentration below the DL for the measuring technique. Use of an in-facepiece measuring technique with a lower DL might have resulted in higher calculated SWPFs.

Table I. Calculated and Assumed Protection Factors and Termination Data for the Test Runs

Test run	Mean SWPF	Median SWPF	5 th percentile SWPF	Assumed PF	Data pairs accepted	Data pairs rejected	DL pairs remaining	Case type
Plnk1	615	350	200	62	107	1015	29	3
Plnk2	402	351	208	152	1448	376	0	1
Plnk3	2769	2330	165	164	1193	1228	1094	2
Plnk4	2053	1574	850	375	548	1514	0	1
Plnk5	2442	3749	903	351	100	2060	95	3
Plnk6	2027	1336	352	352	205	1154	98	2
Plnk7	1839	2660	2219	220	100	1389	100	3
Plnk8	3043	2998	2790	278	102	1471	102	3
Plnk9	1144	768	260	260	1020	638	29	2
Plnk10	864	431	206	206	460	1097	18	2
Plnk11	2488	3087	2802	280	100	1756	96	3
Plnk12	831	376	196	196	677	762	45	2
Plnk13	1197	1026	515	292	1378	422	0	1
Plnk14	2221	1122	390	375	486	1512	0	1
Plnk15	1525	1227	1119	111	100	1715	100	3

For nine of the test runs it was possible to calculate actual values for median and 5th percentile SWPF, i.e. the iterative process terminated successfully as Case 1 or Case 2. These are presented separately in Tables II and III. For test runs Plnk 3 and Plnk 6 only about 100 non-DL pairs resulted from processing the raw data, but for the other successful test run calculations more than 400 non-DL data pairs resulted from the process.

Table II. Calculated Median and 5th Percentile SWPFs for Those Runs that Terminated as Case 1

Test	Median	5 th percentile	Observations
Plnk2	351	208	Beard, Spectacles
Plnk4	1574	850	Talked
Plnk13	1026	515	Spectacles, small face
Plnk14	1122	390	Spectacles

Table III. Calculated Median and 5th Percentile WPFs for Those Runs that Terminated as Case 2

Test	Median	5 th percentile	Observations
Plnk3	2330	164	
Plnk6	1336	352	
Plnk9	768	260	Spectacles
Plnk10	431	206	
Plnk12	376	196	Beard, Spectacles

The values of the 5th percentile SWPF for those test calculations that terminated successfully are much higher in comparison with the APF of 20 for this RPD. They ranged between 164 and 850 with a mean of 366. The medians ranged between 351 and 2330 with a mean of 1035. To meet the European Standard, laboratory tests on this type of device are permitted an inward leakage of no more than 2% equivalent to a protection factor of at least 50.

For the remaining six test runs, the protection factor values were calculated to the point of approximately 100 acceptable data pairs remaining, i.e. the iterative process terminated as a Case 3 (see Table 4). This means that the challenge concentration was not high enough for the iterative process to terminate conclusively, and so termination was forced due to lack of data. In this case, the actual median

and 5th percentile SWPF could not be calculated, as not all of the biased data had been eliminated. In such cases, it was possible to calculate a *minimum* 5th percentile SWPF (i.e. a value which the 5th percentile SWPF, achieved during that test, cannot be less than). For example, in the case of PInk1 (see Table I) it cannot be said with any certainty that the 5th percentile SWPF was 200. It can be said, however, that it was not less than, and was probably greater than, the assumed protection factor of 62 (Table IV). The fact that Case 3 applies to six out of the fifteen tests indicates that the challenge concentrations required to accurately measure the SWPF of this RPD with this in-facepiece measuring technique are higher than those present during these 6 test runs.

Tables II, III and IV include observations regarding the wearing of this loose-fitting RPD. There does not seem to be any correlation between calculated SWPF and interference with the face seal quality due to the wearing of spectacles or facial hair or to having a small face.

Table IV. Calculated Lower Limits of the 5th Percentile SWPF for Those Runs that Terminated as Case 3

Test	Lower limit of 5 th percentile	Observations
PInk1	62	
PInk5	351	Spectacles, Small face.
PInk7	220	
PInk8	278	Spectacles
PInk11	280	
PInk15	111	Beard, Spectacles

DISCUSSION

Using all available data from all 15 test runs together, gave SWPFs for the RPD of 1005 and 232 for the median and 5th percentile, respectively. Considered individually, nine of the test runs performed provided enough useful data to be able to calculate a SWPF for the RPD, on that single occasion of use. This was despite much of the data being rejected due to the low challenge concentrations, and the high DL of the PID's. However, only 2 of these test runs resulted in less than 400 non-DL data pairs. This RPD provided high levels of protection in the tests, the lowest calculated 5th percentile SWPF being 164, well above the APF, of 20.

From the six remaining test runs, a *minimum* value was calculated for the SWPF. The 5th percentile SWPF was, without exception, well above the APF for this class of device. For these test runs to have produced more useful information (i.e. *definite* values) an improved in-facepiece concentration measuring technique (with a lower DL) or a higher chamber challenge concentration would have been required. It is unlikely that any workplace situation would provide higher challenge concentrations than

those experienced during this work, as suitable engineering controls should be in place; an improved in-facepiece concentration measuring technique would be required.

The high levels of protection achieved here might in part be due to the non-strenuous nature of the work. The volunteers were never short of breath, nor were they required to speak, which reduced the demands made of the respiratory equipment. The work activity was not carried out in a restricted space or awkward position, which would carry the risk of having the device knocked out of place on the wearer. The clean air flow out of the device was not affected by extreme or even moderate movement of the head, and no strong draughts were created from the work activity. On the other hand, the volunteers were occupied with the task in hand, and so were unable to fully concentrate on wearing their RPD correctly. However there was no observed incorrect wearing of the device. In laboratory tests, the subject has little else to think about, and so may achieve a better fit than they would when preoccupied. Under more strenuous circumstances the device might not perform as well, possibly more in line with the accepted UK APF.

By comparison, an actual workplace study of SWPFs provided by a higher class of airfed device supported the UK APF of 40 for that device (Bolsover, Rajan and Vaughan: 2005). However, the challenge concentration was often not high enough to confidently measure the SWPF of the device. In that study only 11% of the data collected was considered valid (compared to 33% in our study) due to the low challenge concentration within the work area, compared to the detection limit of the measuring technique. Some of the data gave protection factors in excess of 2000 and notably, under conditions of high challenge concentrations, the calculated PF was high. The device was being worn by vehicle paint sprayers, a type of work which is physically more demanding having to be carried out in more awkward conditions than those experienced during our print industry simulation studies. There was evidence of poor practice in the use of the RPD by paint sprayers, as well as scope for interference with the airflow function of the device due to the awkward physical conditions and strong external airflows from both the paint spraying activity and the extraction systems. During a recent laboratory chamber based study it was noticed that the operation of a fan within the chamber had a significant detrimental effect on the protection given by an air-fed RPD which is in common use in the paint spraying industry (Clayton and Frost: 2005).

CONCLUSIONS

The type of airfed respiratory protective device used in this study has an assigned protection factor (APF) of 20 in the United Kingdom. When this value was set, no suitable data was available on the actual performance of this type of device in the workplace.

This work concludes that this continuous airfed loose-fitting RPD, is capable of providing a level of protection well in excess of that indicated by the accepted UK APF of 20, when used in circumstances similar to those experienced in this study. This will be the case if the RPD manufacturer's instructions are followed, the type of work undertaken is relatively light and there are no significant sources of ambient air disturbance that could interfere with the airflow around the RPD.

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