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TNO report

DV2 2005-A15

Respirator Field Trials

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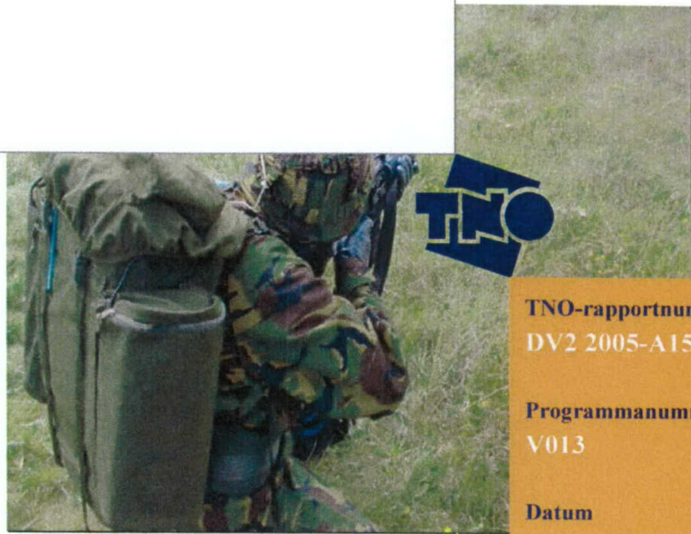
Gasmasker veldproeven



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Probleemstelling

Uit een eerdere studie is gebleken dat – mits verstrekt in de juiste maat, goed afgesteld en na voldoende training – het Nederlandse FM12-gasmasker de gebruiker in rust een beschermingsniveau biedt dat aan de eisen voldoet. Het beschermingsniveau tijdens daadwerkelijke inzet dient echter nog te worden bepaald. Een methode, ontwikkeld om de bescherming van het gasmasker in het veld te meten, toonde reeds aan dat bij het uitvoeren van oefeningen zoals hardlopen, kruipen en springen de beschermingsfactor zoals gemeten in rust een te rooskleurig beeld geeft van het daadwerkelijke beschermingsniveau. Voorliggende studie geeft inzicht in het beschermingsniveau van het Nederlandse gasmasker tijdens realistische NBC-oefeningen.

Beschrijving van de werkzaamheden

Gelaats- en uitlaatventiellekkage leveren de belangrijkste bijdrage aan het verminderd functioneren van gasmaskers. Met speciaal ontwikkelde apparatuur werd tijdens een drietal veldproeven de lekkage van het gasmasker gemeten. Aanvullend werden de bewegingen van het masker en de druk in het masker geregistreerd. De druk in het masker werd vervolgens omgezet in een ademhalingspatroon.

Twee van de drie veldproeven zijn gehouden in Engeland en waren georganiseerd door DSTL, TNO's Engelse zusterinstituut, dat over vergelijkbare apparatuur beschikt. Tijdens de eerste twee veldproeven werden door militairen realistische oefeningen uitgevoerd zoals schieten, hardlopen, voertuig ontsmetten en het lopen van een verkenningspatrouille. Tijdens een derde oefening op vliegbasis Leeuwarden werd in een schietsimulator het effect van terugslag op de bescherming van het masker gemeten. Gedurende alledrie de veldproeven waren de soldaten gekleed in volledige NBC-uitrusting om ook de effecten van warmte, gewicht en bewegingsbeperking mee te nemen en de oefeningen realistischer te maken.

Resultaten en conclusies

Analyse van de veldproeven leert dat het Nederlandse FM12-gasmasker lang niet altijd voldoende bescherming biedt. Hoewel geen directe correlatie kon worden gevonden tussen de beschermingsfactor enerzijds en specifieke bewegingen zoals schieten, of inspanning gekoppeld aan zware ademhaling anderzijds, is de algemene trend dat bij extreme bewegingen en zware inspanning het beschermingsniveau van het masker (te ver) daalt. Het ademvolume tijdens inspanning stijgt van ongeveer 20 l/min tijdens de oefening tot maximaal 100 l/min.

Toepasbaarheid

Het gemeten beschermingsniveau kan dienen als aanzet voor onderzoek naar vermindering van gelaatslekkage. Daarnaast kan de opgedane kennis over het beschermingsniveau van (delen van) oefeningen dienen als uitgangspunt voor het opstellen van doctrines, wat wel en niet te doen wanneer het masker wordt gedragen. Tot slot kunnen de vastgestelde ademhalingspatronen worden omgezet in testen waarbij de capaciteit van de filterbussen realistisch wordt bepaald. Nu gebeurt dat nog met relatief lage luchtsnelheden. Inmiddels is het onderzoek voortgezet onder additionele financiering van het KPU-bedrijf. Daarbij worden onder andere klimatologische omstandigheden betrokken.

PROGRAMMA	PROJECT
Programmabegeleider A.S. de Koning, CDC/MGFB	**Projectbegeleider** Jacques Engelen, KPU Bedrijf
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Frequentie van overleg Met de programma/projectbegeleider werd 4 maal gesproken over de invulling en de voortgang van het onderzoek.	**Projectteam** L.A.W.M. Steenweg, ir. H.F.A. Trimbos, dr. S. van der Gijp, R.J. Schimmel, ing. B. Nijboer, G.S. Richardson (DSTL).

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Samenvatting

Uit een eerdere studie is gebleken dat, mits verstrekt in de juiste maat, goed afgesteld en na voldoende training, het Nederlandse FM12 gasmasker in staat is om in rust voldoende bescherming te bieden. Het beschermingsniveau tijdens daadwerkelijk inzet dient echter nog bepaald te worden. Een methode ontwikkeld om de bescherming van het gasmasker in het veld te meten toonde reeds aan dat bij het doorlopen van een oefeningen zoals hardlopen, kruipen en springen de beschermingsfactor zoals gemeten in rust een te rooskleurig beeld geeft van het daadwerkelijke beschermingsniveau van het masker. In de voorliggende studie wordt inzicht gegeven in het beschermingsniveau van het Nederlandse gasmasker tijdens realistische NBC-oefeningen.

Tijdens een drietal veldproeven werd gebruik gemaakt van speciale voor deze metingen ontwikkelde apparatuur om de lekkage van het gasmasker te meten. Gelaats- en uitlaatventiellekkage zijn verantwoordelijk voor de belangrijkste bijdrages van het mogelijk slecht functioneren van gasmaskers. Aanvullend aan de lekkage metingen werden ook de bewegingen van het masker en de druk in het masker geregistreerd. De druk in het masker is vervolgens om te zetten in een ademhalingspatroon. Zowel negatieve druk als gevolg van zware ademhaling en beweging kunnen oorzaken zijn voor een toename in lekkage.
Twee van de drie veldproeven zijn gehouden in Engeland en waren georganiseerd door DSTL, ons Engels zusterinstituut, welke over vergelijkbare apparatuur beschikt. Tijdens de eerste twee veldproeven werd realistische oefeningen uitgevoerd door militairen zoals schieten, hardlopen, voertuig ontsmetten en het lopen van een verkenningspatrouille. Tijdens een derde oefening op de vliegbasis Leeuwarden werd in een schietsimulator geschoten om het effect van terugslag op de bescherming van het masker te kunnen meten. Gedurende alle drie de veldproeven waren de soldaten gekleed in volledige NBC-uitrusting om ook zo ook de effecten van warmte, gewicht en bewegingsbeperking mee te nemen en de oefeningen realistischer te maken.

Analyse van de veldproeven leert dat het Nederlandse FM12 gasmasker lang niet altijd voldoende bescherming biedt. Hoewel geen directe correlatie kon worden gevonden tussen de beschermingsfactor enerzijds en specifieke bewegingen zoals schieten, inspanning gekoppeld aan zware ademhaling anderzijds, is toch overall een trend te zien dat bij extreme bewegingen en zware inspanning het beschermingsniveau van het masker (te ver) daalt. Overigens lopen de resultaten tussen militairen onderling sterk uiteen. Het ademvolume tijdens inspanning stijgt van ongeveer 20 l/min tijdens de oefening tot maximaal 100 l/min.

Het gemeten beschermingsniveau kan als basis dienen in studies die inzicht geven in hoeveelheden slachtoffers tijdens een NBC-aanval. Daarnaast kan de opgedane kennis over het beschermingsniveau van (delen van) oefeningen dienen als uitgangspunt voor het opstellen van doctrines, wat wel en niet te doen wanneer het masker gedragen wordt. Tenslotte dienen de vastgestelde ademhalingspatronen omgezet te worden in realistische testen waarbij de capaciteit van de filterbussen realistische wordt bepaald. Nu worden filterbussen nog getest met relatief veel lagere luchtsnelheden.

Ondertussen is het onderzoek voortgezet onder additionele financiering van het KPU bedrijf. Tijdens het vervolgonderzoek worden onder andere klimatologische omstandigheden bij het onderzoek betrokken.

Summary

Previous studies show that when the Dutch AVON FM12 respirator is issued in the right size, adjusted properly and when sufficient training is provided, the mask can provide adequate protection in rest. The protection level during actual use still needs to be quantified. A method, which was designed to measure the protection factor in the field, already indicated that during exercises like running, jumping and crawling, the protection factor as measured in the laboratory give a too prosperous image of the actual protection offered by the respirator. In the current study insight is given in the actual protection factor during realistic NBC-exercises.

During three field-trials special designed equipment was used to measure leakage inside the respirator. Both face seal and outlet valve leakage are the most contributing factors to the possible failure of masks. Additional to the leakage measurements, movement of the respirator and pressure were monitored as well. The pressure inside a respirator can directly be correlated to a breathing pattern. Both negative pressure, caused by heavy breathing and movement of the mask can contribute to leakage of the maks.
Two field trial were conducted in the United Kingdom and were organised by DSTL, our English sister institute, which has similar specialised equipment available. During both field trials realistic NBC-exercises were conducted like, shooting, running, vehicle decontamination and walking a patrol. The third field trial was conducted at the Airbase Leeuwarden. In this field trial a shooting simulator was used to study the effect of recoil in more detail. During all three field trials the soldier wore full NBC protective gear in order to include negative effects from heat, weight and dexterity, which added to the realistic nature of the scenarios.

Analysis of the data shows that the Dutch FM12 respirator not always provides sufficient protection. Although no correlation could be found between protection factor on one side and specific movements like shooting or heavy breathing caused by extreme exertion on the other side, a trend is visible in which extreme movements and heave breathing do cause a serious reduction in the protection factor. During these exercises the breathing volume rises from approximately 20/lmin to 100 l/min.

The protection factor measured during the trials can serve as a base for modelling studies which predict the number of casualties after an NBC-attack. Additionally the knowledge gained in this study can serve as input in drafting operation doctrines, which actions to make and which to leave. Finally, the breathing patterns recorded serve as input for realistic breakthrough experiments with NBC-canisters. Currently, much lower air velocities are used to test canisters as were recorded during this study.

Meanwhile this research is continued in an additionally funded research program by the KPU-Bedrijf. During this research program, amongst others climatological factors are included.

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1 Introduction

In previous work, test equipment was developed for the measurements of the protection offered by a respirator in the field [1]. This apparatus was used to establish a correlation between the protection factor on one side and movement or breathing on the other side. Also a representative field protocol for the military was developed and tested, which reassembles the operational use of a respirator more closely than the current NATO-laboratory protocol [2].
No correlation was found between the various parameters. However, the representative field protocol showed lower protection factors than the laboratory protocol. These reduced protection factors, for a more operational setting, triggered the necessity of measuring under even more realistic scenarios.
In this report the results are described of three field trials. These trials, amongst others, comprised running, shooting, decontamination and digging exercises. During these exercises the respirators were worn by trained soldiers. Two of the trials were conducted in the United Kingdom under the flag of the ANNCP[1]. The trials itself are described in more detail in Chapter 3.
For the second trial new equipment was developed. This equipment is described in Chapter 2. The data for each trial, generated with the old and new system, are presented and discussed in Chapter 4 to 6. Finally, in Chapter 7, the combined data are discussed. In Chapter 8 conclusions will be drawn and recommendations are made.

This report is based on two projects. The first project entitled 519d Protectiefactor te velde II with internal project number 15234 was funded by the programme on Passive NBC Defence. The second project entitled PF te velde 2001, with internal project number 12717 was funded by LBBKL, KPU-Bedrijf.

1 ANNCP: Anglo, Norwegian, Netherlands Collaboration panel.

2 Equipment

In this report two sets of equipment were used to measure the field protection factor. The first system, further referred to as old system, has been developed in previous projects [1, 2]. The second system, further referred to as new system, was built before the second field trial in Porton Down.

During the trials both face seal and outlet valve leakage is measured. In the report 'protection factor' is used to describe the amount of leakage. The relation between leakage and protection factor (pf) is given in the following equation:

$$Pf = \frac{1}{(Faceseal\ and\ outlet\ valve)\ leakage + Canister} = \frac{Concentration\ Ambient}{Concentration\ Mask}$$

In this report the contribution of the canister, penetration of particles and breakthrough of gases, is not taken into account. Note that adding this contribution will only lower the protection factor values described in this report. Also note that when official respirator terminology is used, instead of merely protection factor, the term 'simulated workplace protection factor' should be used. For reasons of simplicity the terms 'simulated workplace' are omitted.

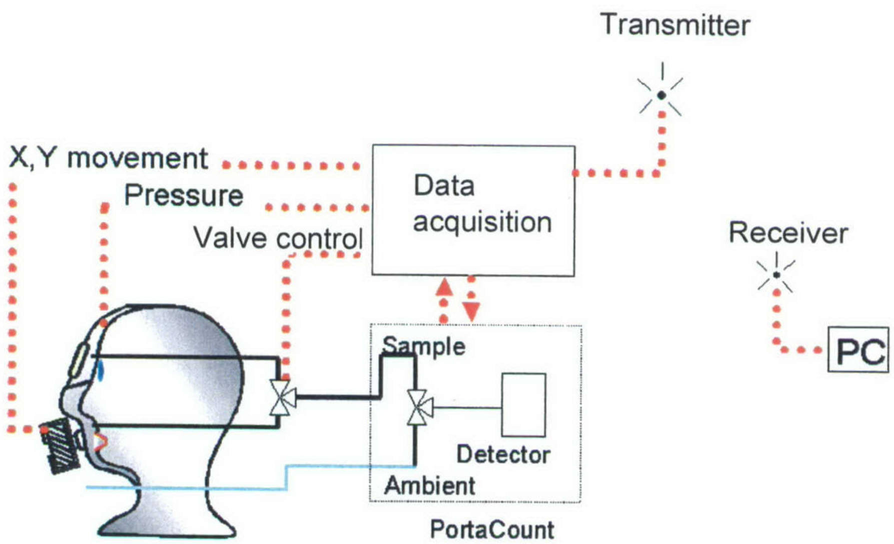

Figure 1 Schematic overview of the old system for measuring the protection factor of respirators in the field. Note that for the trials described in this report, the valve in the bag pack was removed, instead only sampling took place form inside the mask.

2.1 Old system

The old system is shown schematically in Figure 1. The apparatus is described in great detail in reference 1. It is important to realize that the old system is based on the use of one Portacount (Model 8020; TSI) near the mask and one Portacount in the test surrounding, but not necessary close to the masks. The distance between this additional Portacount and the soldier varied from 1 to 300 meters.

Next to the protection factor, which was measured every second, the old system was used for the measurement of movement and pressure. Both pressure and movement were monitored 20 times a second. The movement of the mask was measured horizontally (X-direction) and vertically (Y-direction). The measurement of pressure is representative for the breathing pattern of the test person. Due to the data-link it is possible to see directly whether the mask is fitted properly or when large drops in protection factors occur. The data can be fitted to video images by the use of events. An event is an extra signal, given from the laptop, placed in the datasheet at some desired point in time in order to link the data to a specific action. The valve control and the option to measure in the eye-region were not used during the field trials described in this report.

System 1 generates a huge amount of data, more than excel can coop directly. Normally, only the first 30 minutes were transferred directly to the excel sheet.

2.2 New System

The new system, which was developed for this project, is shown in Figure 2. The protection factor was measured with two Portacounts on the soldier. Each Portacount was connected to a data logger (Palmtop; Compaq, Ipaq pocket PC). The use of two Portacounts allowed simultaneous sampling in the mask and outside, but near the mask.

Figure 2 Photo of the new system which comprises of two Portacounts, which are individually coupled to data loggers. Also visible is the portable video-recorder which is fitted to a camera, which on its turn is placed on the helmet.

The number of particles was sampled each second. A program entitled 'Portacountlogger' was written for the data-communication between the Portacount and the palmtop.
In addition to both Portacounts, the back bag contained also a video recorder (Sony digital video cassette recorder GV-D1000E). The video recorder was connected to a camera (digital colour CCD). The camera, which was mounted on a standard helm, was fed by a power pack (12V).

During the trials the exercises with both the old and the new system were recorded with a digital video camera (Sony digital handycam DCR-TRV11E).

3 Trials

In this report three trials are described; two in the UK and one in the Netherlands. The trials in the UK were organized by DSTL. Both trials in the UK took place under the flag of the ANNCP 3/4. The UK and the Netherlands participated actively during the trial. Norway provided an observer.

During each trial, the soldiers were allowed to done their masks as they would have donned it during actual use. No improvements were made with respect to size or adjusting of the head harness.

3.1 Longmoore

The first trial in the United Kingdom took place on the Longmoore range from November 11 to 15 2002. The trial took place on two shooting ranges. Both ranges were more or less flat terrains, with mainly short grass. The ranges were fitted with automatic shooting targets. During the trials, the temperatures were relatively low it was cold (5-10°C) and it rained frequently.
Only the old system was used in this trial. The trial was conducted with volunteers from the UK army, either the DSTL contact person, Maj. Angus Mcleod or instructors from the NBC school. The army volunteers wore their UK NBC suit, booth and gloves and shot with UK rifles. The FM12-mask was fitted with a UK canister. During the first trial, shooting exercises were performed, either on position or during patrolling.

3.2 Porton Down

The second trial took place at a range near Porton Down on June 16 to 19, 2003. The trial took place at two locations. Both systems were used. One site consisted of a shooting range; Rough terrain, with long grass and a deep trench. The second site consisted of various locations at the NBC school in Porton Down.
The whether on the first two days of the trial was sunny, temperature around 25 °C. The last two days were cloudy with a temperature around 20 °C.
The trial was conducted with two Dutch air force volunteers from the air base Leeuwarden; Gerard Kok and Aage de Vries. During the trial they wore the Dutch NBC equipment (FM12; M2000) and shot with the Dymaco rifle.
During these second trials both the hart rate and the temperature were monitored of the volunteers.

Several realistic exercises were performed:

- shooting;
- patrol (with shooting);
- NBC recognisance;
- vehicle decontamination;
- digging a foxhole;
- various exertion and team exercises.

3.3 Leeuwarden

The trial in the Netherlands was held on August 28 and 29. The main purpose of this trial was to use a shooting simulator. The rifles in this simulator have recoil, but do not generate particles. The lack of extra particles should be beneficial for the accuracy of the measurements. Inside the simulator the volunteers from the air base Leeuwarden wore the standard NBC equipment (FM12, M2000). During various electronic scenario's, the Dymaco and the Mag were used. Because ambient air particles were removed by the air-conditioning system of the simulator, artificial particles were generated using candles. Both systems for measuring the protection factor were used. Additionally two experiments were performed outside using the field protocol. Again Gerard Kok acted as volunteer, he was assisted by two colleagues of the Air force base.

4 Long Moore

4.1 Base line

As a basis of the measurements four baselines were recorded with the old system. A typical baseline recording consists of:

- rest;
- nodding yes;
- shake one head (No);
- heavy breathing;
- speech.

All actions are recorded for one minute. In Table 1 the results of three baseline recording are given. During the recording, due to the pressure- and movement sensors a clear distinction can be made between each section, see Appendix B.

Table 1 The results of three baseline recordings of the protection factor measurement. H.Breathing means heavy breathing.

Soldier	Rest	Yes	No	H. Breathing	Speech
1	60000	13000	86000	54000	23000
2	22000	74000	43000	60000	5500
3	12300	43000	24000	58000	4800
Average	21000	68000	39000	57000	6900

Table 1 clearly shows that for each action, each individual has a protection factor well above 10,000, except speech. This proves again that during speech particles were generated, see also reference 2. Artificially generated particles lower the protection factor. In the first few second of heavy breathing a similar drop in protection factor was found as well. Apparently, some particles are generated by an unknown mechanism during this stage of the baseline.

4.2 Patrol, walking and shooting

During the Long Moore trial only the old system with one Portacount on the soldier was available. In order to avoid the effect of additional locally particles generated by shooting, in addition to runs with firing, similar runs were repeated without firing, in a so-called simulation-run.

The UK soldier Stuart started the simulation run with a protection factor of approximately 19,000. The average protection factor during the run was 5200; based on an ambient air concentration of 6200 particles/cm^3. Especially between 200 and 400 seconds, the time Stuart was running, kneeling and crawling, the protection factor was considerably lower than average and the required standard. As can be seen in Figure 3 the run in which Stuart actually fires results in a much lower average protection factor. Although no visible in the video data, apparently Stuart removed his mask for some time, since the protection factor dropped to 1.

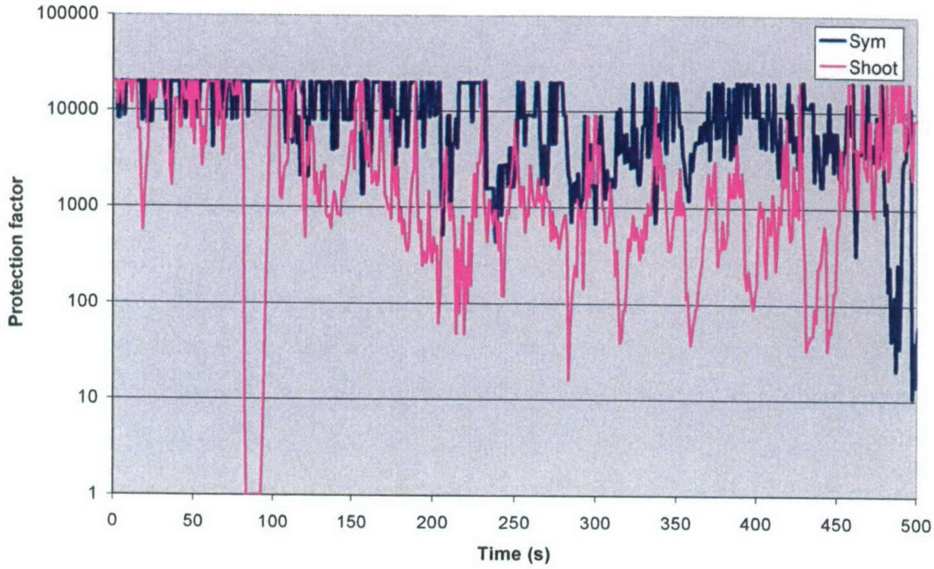

Figure 3 Protection factor results of two runs, one with shooting (shoot) and one in which the same scenario was followed without shooting (sym). Results were obtained with Stuart wearing the old system.

Both exercises were repeated a second soldier (Angus), the data of this exercise is visible in Appendices C and D. During the exercise with life firing Angus started out with a protection factor of above 6000. The average protection factor was approximately 3200 as measured with an average ambient concentration of 3850. During the exercise the protection factor dropped frequently below 1000. During the simulation run comparable protection factors were found. The maximum minute volume of air through the mask was 100 l/min, which correspondents to a maximum flow of 315 l/min through the canister.

During the Longmoore trial several other exercises were conducted in which the soldiers shot in different positions and wither with single shot or automatic fire mode. Since particles generated by shooting decreases the protection factor artificially and since not always an increase in ambient particles is observed after firing, see also Appendix E, the resulting protection factor data is not very reliable and therefore presented in this report.

5 Porton Down

5.1 Human Factors

As experiment during the second trial in the United Kingdom, both hart rate and body temperature were measured.

5.1.1 *Temperature*

Figure 4 shows the temperature profile during the trial. Note that the temperature was recorded during the whole trial, including the week before and several days after. The temperature was recorded each 10 minutes. The sensors were placed near the heart region of the volunteer. On average the temperature underneath the NBC suit and the t-shirt was 33 and 30 °C.

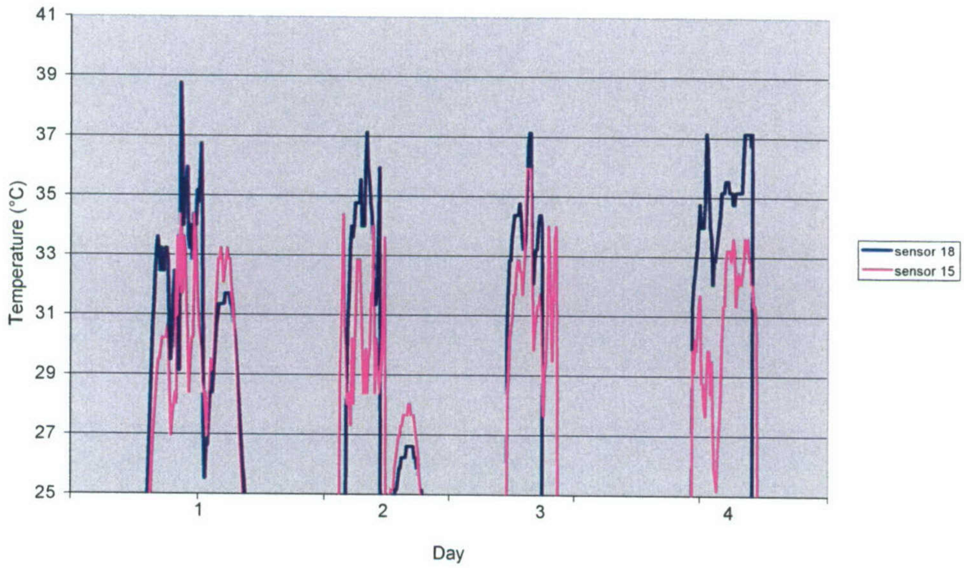

Figure 4 Results of the temperature sensors.

Although no correlation was made between the temperature and the exercise, it can be seen that during day 3, during which vehicle decontamination and digging took place no more increase in temperature was found compared to the other days.

5.1.2 *Hart rate*

In Figure 5 the hart rate during the various exercises is shown. Again, no correlation is made to a specific exercise. It is visible that the hart rate increases from around 70 to a maximum of approximately 170. Note that the data showed various spikes above 200, these single points were omitted from the plot.

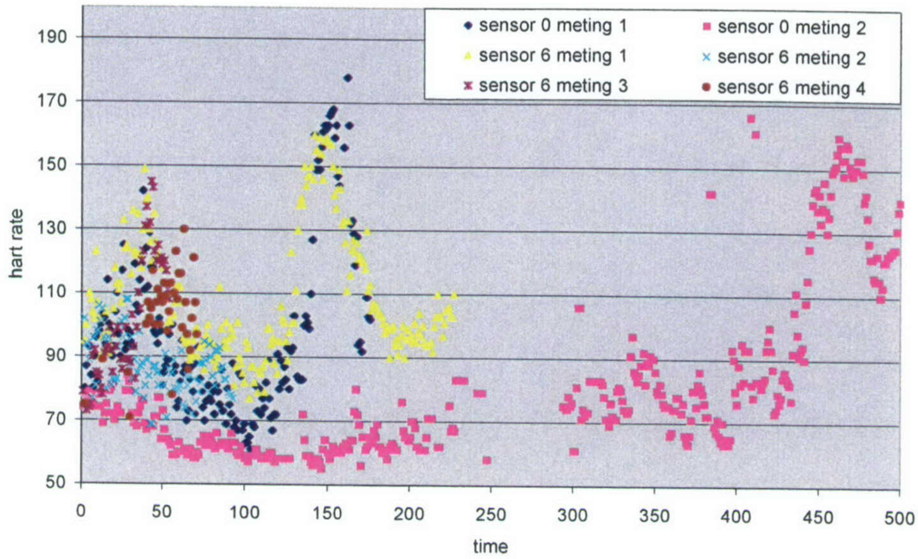

Figure 5 Results of the hart rate sensor.

5.2 Decontamination

The two volunteers were dressed with the impermeable Dutch suits. Although these suits are no longer in active service, currently no alternative is present within the Dutch Army. The two volunteers wore their suit directly on their battle dress.
The two volunteers performed a decontamination exercise in which a tank was cleaned in a time period of one hour. The decontamination exercise consisted out of pumping, scrubbing, rinsing and climbing on and off the vehicle. A stimulant decontaminant was used in a spray bottle, which had to be pressurized by means of pumping. Figure 6 is a snap shot off the exercise.

During the exercise the ambient temperature was around 22 °C. Both volunteers noticed that during the exercise the temperature underneath their suits increased remarkably.

Figure 6 Decontamination in impermeable suits. First the tank was sprayed using the can on the left below, then the tank was scrubbed.

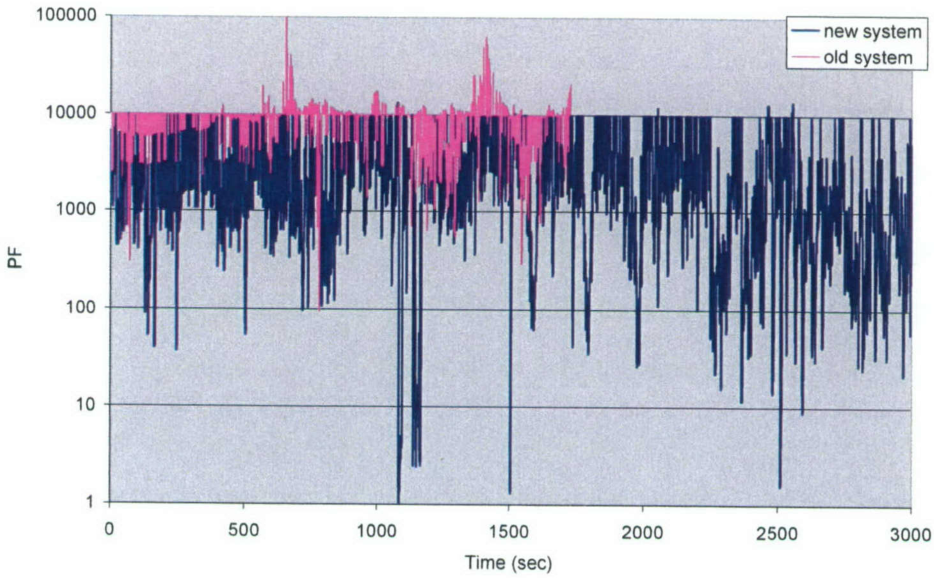

Figure 7 Protection factor measured with both systems during the decontaminate exercise.

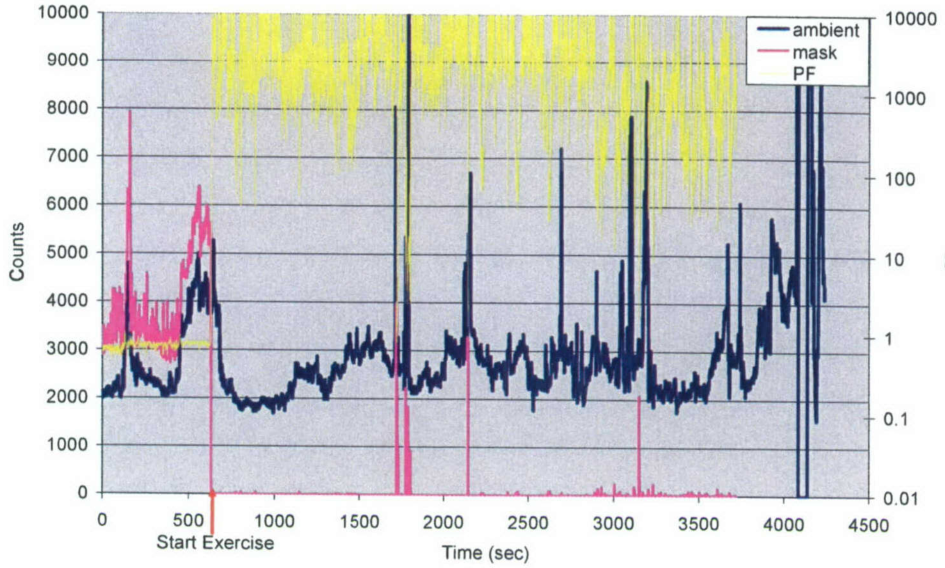

Figure 8 Counts measured with the new system during the decontamination exercise.

The average protection factor of the two volunteers was dramatically different. Gerard, known for a bad mask fit, had an average protection factor of 200. During the decontamination exercise the average protection factor of Aage, measured with the new system, was 6000.

In Figure 7 the results of the decontamination exercise are given. Although each second the protection factor was measured with the both systems, the start of the exercises is not coupled and can therefore deviate from each other. In addition during the exercise, the volunteers performed different actions at the same time. Therefore, the drops in protection factor must be seen separately. When no particles were measured, the protection factor was set to be 10000.

Both protection factors show more or less the same pattern for the first 30 minutes. Sometimes a reasonably high protection factor occurred and sometimes a dip. During this first period, the protection factor measured with the old system drops frequent below 2000. The protection factor as measured with the new system drops frequently below 500. During the second half hour the average protection factor as measured with the new system was approximately 500.

Although the use of speech was prevented as much as possible during the exercise. Sometimes a few words were spoken. As indicated before, the use of speech creates an artificial lowering of the protection factor. However, the number and length of the drops in protection factor during the decontamination exercise could not be explained as a result of speech only.

Another possible source of a lower protection factor can be the measurement of artificial generated particles. In Figure 8 it can be seen that in four cases during the exercise the count in both the ambient air and mask increased simultaneously. Although a correction is made for the increase in ambient air particles, still a drop in the protection factor observed in those four cases. Analysis of the data shows that the difference in time for the maxima in ambient air particles and mask particles is different for each of the four peaks. This difference can either be originated by a difference in the accuracy of the time registration of the two palm tops-Portacount combinations or be caused by uncontrollable effects like wind and the time of residence time of particles inside the lungs. Figure 8 shows also that not every increase in ambient air particles lead to an increase in mask particles. Also no large increase in mask particles was found, other than to those originated by an increase in ambient air particles. No effect of speech, if any was used, was found.

In the old-system pressure is measure. Using the calibration described in Chapter 6 the pressure measured as converted to breathing volume. The data was collected per event, in which each event is a part of the exercise. It can be seen from Table 1 that the minute volume of air passing through the mask increased to 26 second half way the exercise, this correspondent to a maximum flow of 82 l/min.

Table 2 Minute volume and max flow measured during decontamination on Aage.

Event	Duration (sec)	Minut Volume (l)	Max flow (L/min)
2	247	17	53
3	69	14	46
4	16	17	55
5	293	21	67
6	15	26	82
7	146	21	68
8	150	24	75
9	208	18	55
10	35	24	74
11	11	26	84

5.3 Digging

During the digging exercise both volunteers wore their NBC equipment over their combat dress. During the exercise a hole was dug. The first part of the exercise was easier, since the top 20 cm of the ground was grass. After this, a layer of extremely hard limestone was situated, which made the second half of the exercise rather heavy.

Again a large difference in the average protection factor was observed between the two volunteers. Gerard, as measured with the new system, had an average protection factor of 200. It can be seen that at after approximately 500 seconds the mask was removed for some time. This period was not even taken into account for the calculation of the average.

The protection factor measured with Aage was higher, 7500, see Appendix G. However, it should be noted that this average was only taken during the first 30 minutes of the exercise. In Figure 9 it can be seen that for Gerard, the second half of the exercise was the worst, probably corresponding to the exhausting circumstances during the exercise.

During digging, the ambient air concentration raised remarkably, see Appendix F. On average the ambient air particle count varied between 1700 and 3500, however during short period of times this number was raised up to 900.000. Because of the large periods of low protection factors, no direct correlation was visible between the increase of ambient air particles and the protection factor.

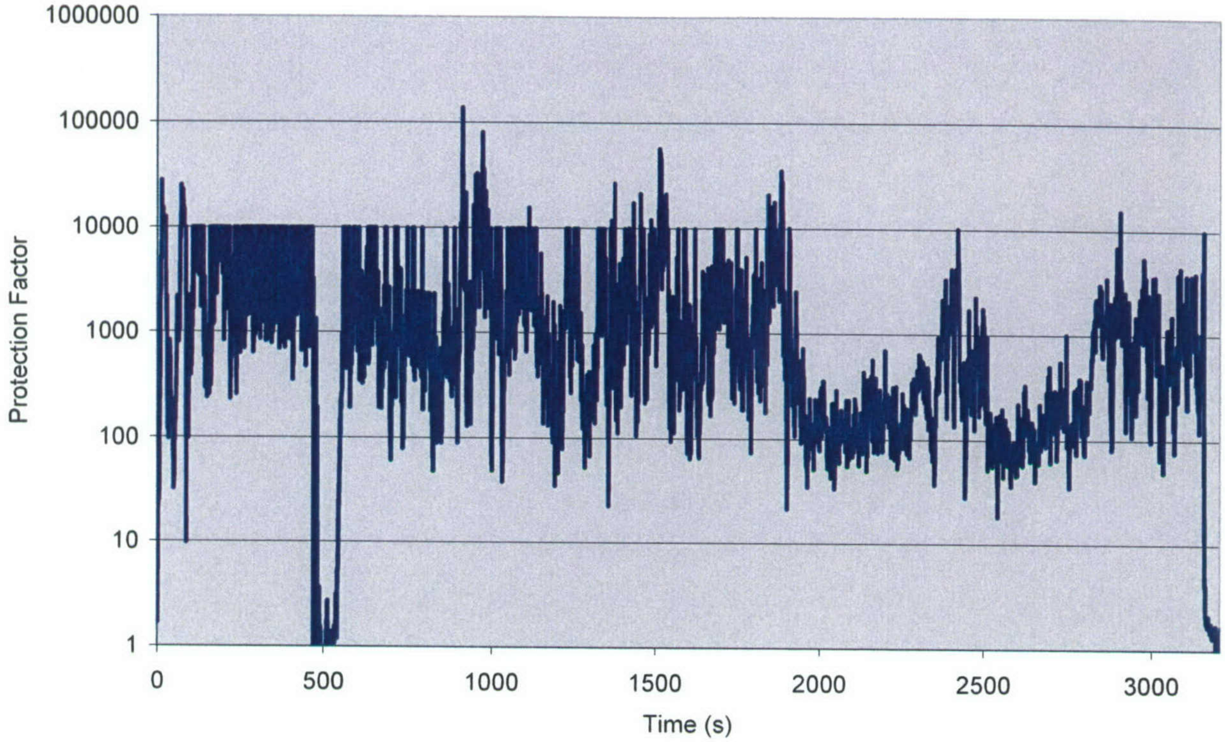

Figure 9 Results of the digging exercise. Measured during the Porton Down Field trial on Gerard.

Figure 10 Both soldiers digging into the first layer of soft grass.

Note that the very low ambient air concentration of 1700, gives rise to accuracy problems. During one second the lowest number of particles, above zero, measured with the Portacount is 0.6. The measurement is this number of particles would result in a protection factor of approximately 2800, which is no where near the required limit of 10,000.

During the exercise, due to the exhausting work and the almost horizontal position of the mask during digging, the mask filled up with sweat. Hence, also the sample line contained a lot of moist. The effect of this moist on the number of counts inside the mask is unknown, but could well be responsible for a high background level of particles and hence a low protection factor.

The pressure difference measured during the exercise proved that digging in lime stone is a severe exercise. During digging the average minute volume increased from 16 to 84l; this corresponds to an average maximum flow which increase from 50 to 265 l/min.

5.4 Patrol walking and shooting

This exercise consisted of walking through rough terrain, kneeling or lying down and firing a weapon. Due to the long grass only shots were fired lying down in the first minute of the exercise. In total nine of these exercises were conducted. The results of these exercises are described in Table 2. The average protection factor during these exercise was 7420 and 113 for both soldiers. An example of the outcome of a run is given in Appendix H. It must be noted that although the latter soldier was fitted with the right size of mask and was an experienced mask user it was very hard to get a proper fit even in rest. The average was taken for both the old and the new system. As with digging and with decontamination during shooting particles were generated. As described earlier in the new system a automatic correction is made, because of the measurement of ambient particles near the mask. The average of the protection factor measured only with the new system for both soldiers was 9900 and 500 based on three and one measurement respectively.

Table 3 Results of the 'waling and shooting' exercises; Soldier 1 is Aage, Soldier 2 is Gerard.

System	Soldier	Avg Pf	Avg Ambient	Min Pf
2	1	8500	20000	500
2	1	10400	7500	200
2	1	11300	14000	300
1	1	6300	40600	1
1	1	4700	4500	2
2	2	500	50000	20
1	2	31	26700	2
1	2	2000	4400	1
1	2	2100	4300	2

As can be seen in Table 3 the average ambient air concentration was relatively high; even without shooting the concentration ranged from 7000 to 40.000 particles/cm^3. During the first two days of the trial on which these exercises took place, the concentration of particles was considerably higher than during the latter days of the trials on which amongst others the patrol with withdrawal exercise took place. The higher number of ambient air particles improves the accuracy of this method for higher protection values.

The exercises lasted approximately for 15 minutes during this time no significant lowering in the protection factor could be observed.

5.5 Patrol, withdrawal with shooting

One of walk and shoot exercises concerned a patrol. First both soldiers had to walk through rough terrain. After a couple of minutes, they met the enemy and they started firing whilst withdrawing. Hence during the first part of the exercise, this exercise deviates from the exercise described in 5.4, in which the soldiers fired during the whole period of the exercise.
In this respect the exercise is different from the exercises described in Paragraph 5.4. The average protection factor was 800 and 1100 for both soldiers respectively. It should be noted that during this scenario it was necessary for the soldiers to shout instructions for safety reasons and hence during the second half of this exercise some particles were generated, creating an artificially lowered protection value.
Because it concerned a shooting-exercise the pressure sensor was not fitted, additionally the camera on the helmet was not equipped with a microphone and for safety reason the hand-held camera was to far from the soldiers to pick up sound. Therefore, it was not possible to abstract the data generated during speech from the data-set.

Figure 11 Walking and shooting with the new system in the Porton Down field trial.

During the first part of the exercise, in which the soldier walked forward during rough terrain the average protection factor measured with the old-system was 1880 and 1600 with the new system. During the second half in which the soldier walked, talked, kneeled and fired the protection factor measured with the old system was 530 and with the new system 675. Although the shooting accounts for some artificial lowering of the protection factor, the factor of two in protection factor is not caused by firing alone. In a period where no firing occurred, the average protection factor was 320 as measured with the new system. Likely, the effect of sweat, movement and heavy breathing is the result the protection factor reduction. This is supported by an increase in the amplitude of the x and y-movement during the second half of the exercise, measured with the new system.
Unfortunately, the conditions for this trial were not ideal. The average number of ambient air particles was approximately 450. Even with an inward leakage of e.g. one particle this meant a protection factor of at most 500. This accounts for lower protection factors during this exercise.

5.6 Exercise

During the last day of the trial, both soldiers participated in a training exercise which consisted out of several games, like e.g. soccer. During the various games the average protection factor 5000 and 3400 measured with the old and the new system respectively. The results generated with the new-system are shown in Appendix H.

5.7 Summary Protection Factor Porton

In Figure 12 the average protection factor is given for the different exercises conducted during the Porton Down field trial. The walking and shooting exercise are itself average data from the various walking and shooting exercises. The required protection factor of 10.000 is not met for both soldiers.

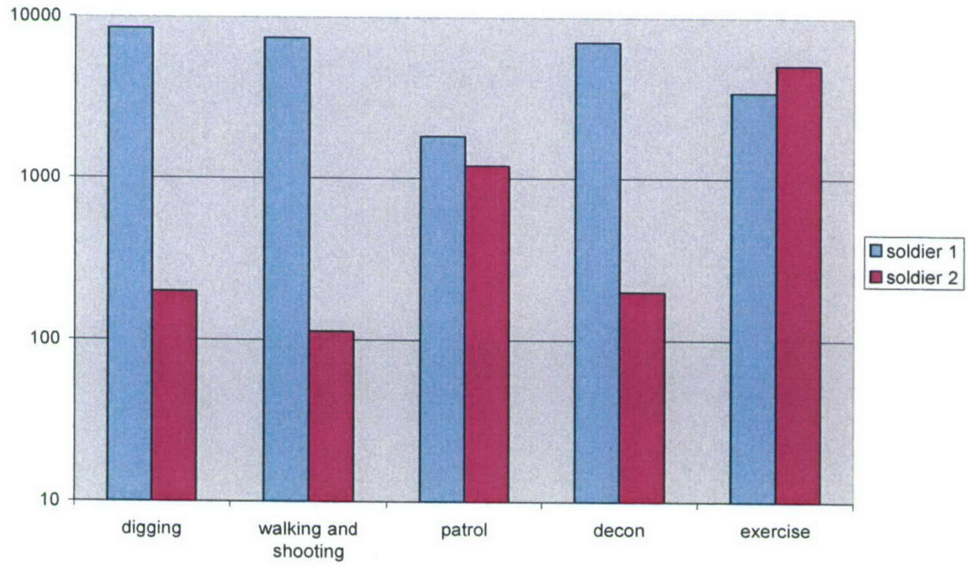

Figure 12 Average protection values of the Proton Down field trial 2003. Soldier 1 is Aage; Soldier 2 is Gerard, both wore the old and the new system alternating.

Taken all the data into account, a statement must be made about the sensitivity of the method. The method as such is based on the number of ambient air particles. This number of particles fluctuates rapidly and can, especially in clean environments be rather limited. This hampers the possibility to measure high protection factors accurately, especially in the case of the old system, in which the second Portacount, which measures the ambient particles, is placed at some distance form the soldier.

Secondly, a limited number of soldiers were tested during the field trials. Due to the realistic nature and therefore the length of the trials and the special apparatus required for these trial it is difficult to scale up the experiments. Also only male soldiers were tested.

Finally, when shooting is part of the exercise, which artificially raises the number of particles drastically, only system two can be used to get reliable data in which the number of ambient air particles is measured locally. Additionally, during speech, which was prevented as much as possible during the exercise, and heavy breathing sometimes particles are generated by the test subject and hence give rise to artificially lowering of the protection factor. Still the authors of this report feel that the (trends in) protection factors shown in this report are valid and reflect the actual protection factor. Finally note that only leakage is monitored with this method, filter breakthrough is not taken into account.

6 Breathing rates

In order to correlate the pressure and the breathing volume a standard measurement was conducted using the Bacou breathing machine, a dummy head and an FM12 mask. For a range of flows the pressure inside the masks was measured. The results of this calibration are given in Appendix C. The average minute volume and the maximum flow of four exercises are given in Table 2.

Table 4 The average minute volume and maximum flow for four exercises. Figures were either abstracted using the Analysis program or when this program could not be used form the Excel files. Between brackets are respectively the name of the test person and the location.

Exercise		Minute Volume (l/min)	Max Flow (l/min)
Decontamination (Age, Porton)	Start	17	53
	Average	21	66
	Max	40	124
Digging (Age, Porton)	Start	18	56
	Average	40	124
	Max	90	282
Patrol and simulated shooting (Angus, Longmoore)	Start	26	83
	Average	63	199
	Max	100	315
Patrol and simulated shooting (Stuart, Longmoore)	Start	16	50
	Average	35	138
	Max	53	166
NATO Standard		30, 50 or 80	

Especially the patrol and simulated shooting comes close to an operational scenario. It is interesting to see that for two individuals with more or less the same exercise the flow through the masks deviates largely.
Although the NATO efficiency tests with GB uses 80 l/min, other test use less flow. These NATO test flows of 30 and 50 comes closes to the average flow found during the exercises. The maximum flow of 282 l/min measured during digging is not reflected in the NATO test-conditions. Note that since pressure is only measured 20 times a second slightly higher values might have occurred during the exercises.

7 Blowers

Its is expected that the use of a blower to assist breathing will increase the protection factor since the pressure inside the mask remains higher compared to no-assisted breathing.
During the first trial in Longmoore three attempts were made to combine the FM12-mask with a Giat-blower. Although, the hose was fitted with a NATO-screw threat no proper connection with a FM-12 mask could be realised during two out of three exercises.
Worst of all during the first trial the battery was low. This causes some of disturbance. Although the measurement of particles continues, in the data-set the mask particles are labelled with the ambient mask particles code.
In the only successful measurement during the first 100 second the average protection factor was approximately 60000 during heavy firing. During the shooting the Portacount which measures ambient air particles was placed at a distance of approximately 20 meters. Near the rifle, locally higher protection factors were measured. Therefore the actual protection factor might have been higher during shooting. After the first period of 100 second, the protection factor drops below 1. Although the drop can not be explained. The value lower than one again proves the statement that near the mask a higher number of particles were present than near the second Portacount, fitted directly to the computer.

During the third trial in Leeuwarden an additional experiment was conducted with a blower. The standard protocol, described in reference 2, was conducted by one person both with and without blower. The result of this trial is shown in Figure 13.

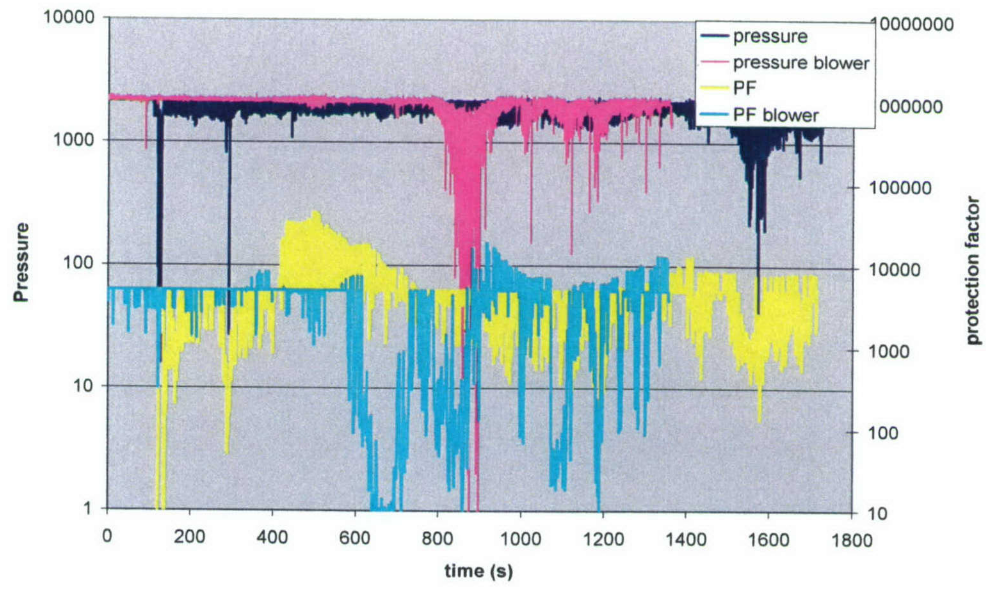

Figure 13 Results of the standard-protocol both with and without blower.

The blower used in this experiment was the 3m-blower. This blower was fitted with two particles filters to prevent particles which are generated by the blower, to enter the mask and consequently influence the meeting.
Whilst the standard protocol was performed, the average pressure in the mask with blower was higher than without blower. In addition the pressure difference, between inhalation and exhalation, was smaller in the case where a blower was applied. This pressure difference did not result in an overall higher protection factor. During the first part of the exercise, the number of particles counted inside the mask was frequently zero. However, after 600 seconds the protection factor reduced dramatically. The reason for this is unknown; also video footages did not show anything unusual.

8 Leeuwarden

8.1 Simulator

The main purpose of the file trial in Leeuwarden was the use of the firing range simulator. During firing in the simulator no particles are released by the rifles. On this way the effect of recoil on the protection factor of the mask can be established more accurately. In the simulator two rifles were used, the Dymaco rifle and the Mag machine gun.

The average protection factor as measured with system one during Dymaco simulation varied between approximately 3000 and 16000. In Figure 14 a detail is shown of an exercise in which the average protection factor was 9000. The period of time was chosen by means of camera footage as the time the volunteer fired his rifle frequently. The time the Dymaco simulator was fired is easy recognisable by the amplitude of the x and y-signal. It is clearly visible that during this period no decrease in the protection factor occurred.

When instead of a Dymaco rifle simulator a heavier weapon, the MAG simulator is used, the outcome of the trial is different. During an exercise in which the average protection factor was approximately 7000 after more than 15 out of 23 shots a decrease in protection factor followed after the shot of shots. The partial results of this exercise are partially given in Figure 15. An example of a complete exercise is given in Appendix J, Figure 23.

In Figure 16 the effect of the recoil is shown on the average movement during shooting. The results were taken from all three field trials. Note that the effect of the recoil on the mask and not the recoil of the rifle itself is measured. Unexpectedly the UK rifle did not show much recoil. In three out of four directions the Dymaco-simulator has less recoil than the actual rifle. The Mag-simulator creates in two directions stronger recoil than the Dymaco; however the short high frequency outburst of bullets of the Mag is not comparable to the single shot mode of the Dymaco.

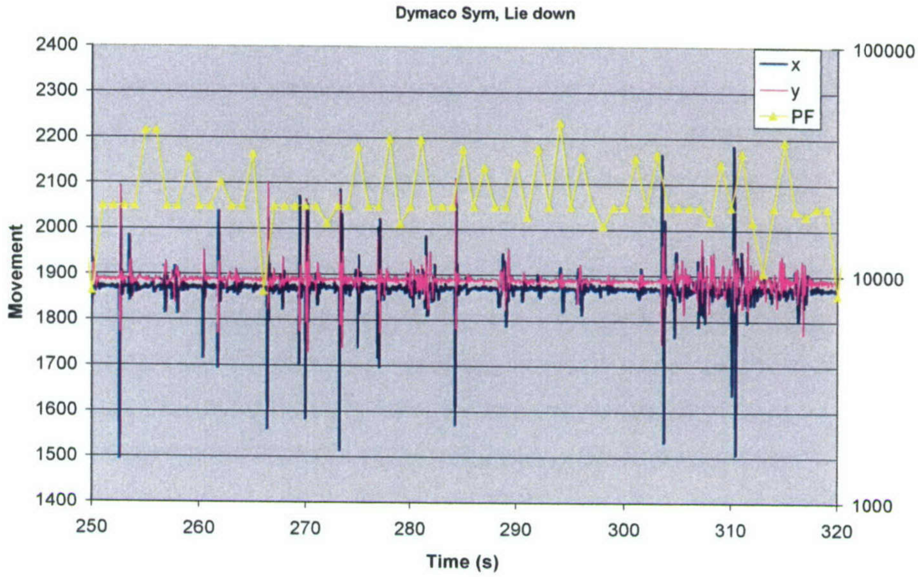

Figure 14 Partial results of a dymaco simulation. Person lies down whilst shooting. On the left axis the x and y movement are shown, on the right axis the protection factor is presented.

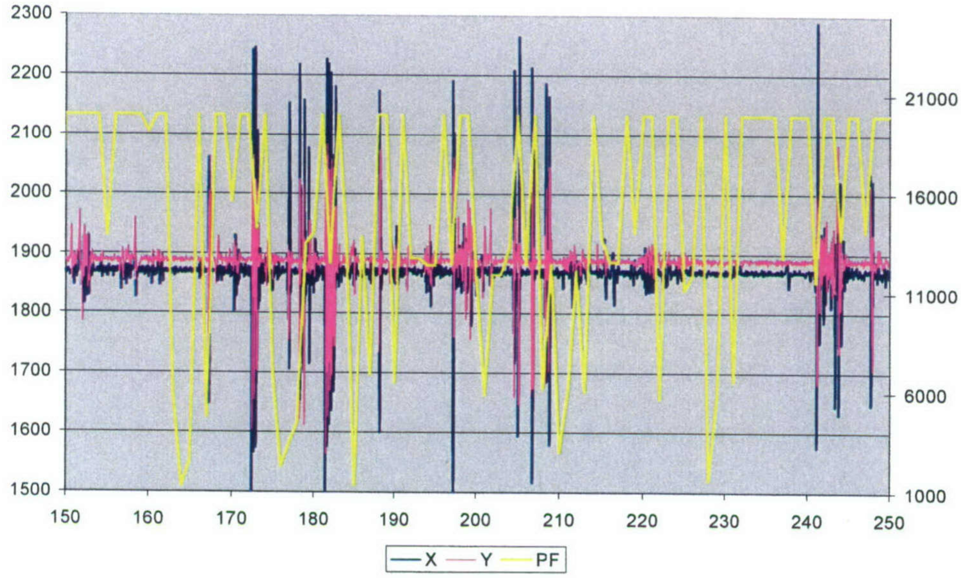

Figure 15 Movement and protection factor during an exercise with a MAG simulator.

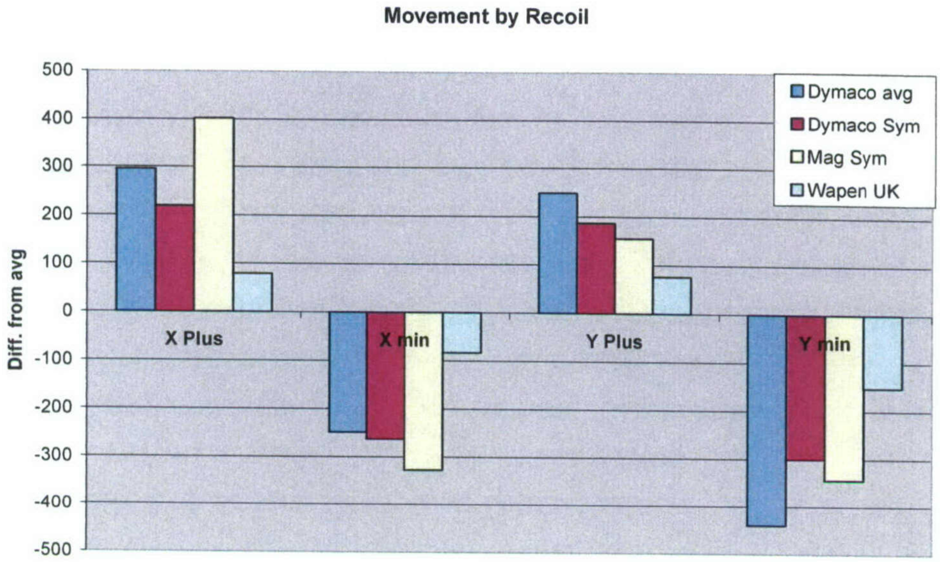

Figure 16 X and Y-Movement caused by recoil. Shown are two actual rifles and two simulants. Movement shown is the deviation from the average movement.

8.2 Standard Protocol

During the trial in trial in Leeuwarden. Soldier 1 performed the standard protocol (reference 2) with the old system. The results of the limited trial are described in Table 5 and Appendix J. Note that during the protocol each exercise is separate from the next by a period of rest; the protection factor during the start of the protocol was well higher than 10,000. Crawling and running, including throwing a grenade resulted in the lowest average protection values. During both these exercises the motion sensors picked up severe movement but more importantly the breathing volume was larger than the volume in other exercises.

Table 5 Results of the standard protocol measured on Gerard. Data shown are average data taken with the data-analysis programme. For movement the data shown are the average data for each exercise minus the overall average. The data of the period of rest between the exercises are omitted.

				Movement			
Action	PF avg	B freq. (Br/min)	B Vol (L/min)	X+	X-	Y+	Y-
Yes	13900	16	20	16	-16	38	-40
No	7990	22	10	52	-70	23	-32
Walking	13800	58	17	38	-37	49	-68
Digging	3320	29	19	42	-45	49	-70
Shelter	4610	23	16	63	-61	76	-89
Crawling	2510	23	30	73	-69	57	-72
Jump	3820	24	19	56	-54	216	-17
Grenade and Run	2100	18	41	63	-69	97	-115
Grenade	6230	23	26	43	-50	68	-67

9 Conclusions

Various exercises, all representing relevant parts of a possible military mission, each have their effect on the protection factor of a respirator. Even with the inaccuracy of the method taken into account it can be stated that for experienced mask users the protection offered by full face masks, in some cases, is insufficient for adequate protection. During the standard protocol crawling and running appeared to yield the lowest protection values.

Breathing rates, recoil of the rifle and sweat each contribute to a decrease of the protection factor. It is not possible yet to correlate each contribution to a reduction of the protection factor. Hence a prediction of a situation in which a mask fails is yet not possible.

Adding a blower to the mask, results in a clearly improved numbers for pressure. However for the single successful experiment this did not result in a higher average protection value. Clearly additional experiments are needed.

During the trials average minute volumes up to 100 l/minute were found. The large breathing volume but also the severe movement of the mask and the sweating of the soldiers indicate that the current NATO standard and in service equipment need to be evaluated.

During the recording of the baseline pattern, speech and the first part of the heavy breathing exercise, particles are generated by the test-subject. Since this gives rise to artificially lowering of the protection factor, at least speech should not be included in the standard Portacount test protocol.

11 Signature

Rijswijk, March 2005

TNO Defence, Security and Safety

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A Calibration Pressure Sensor

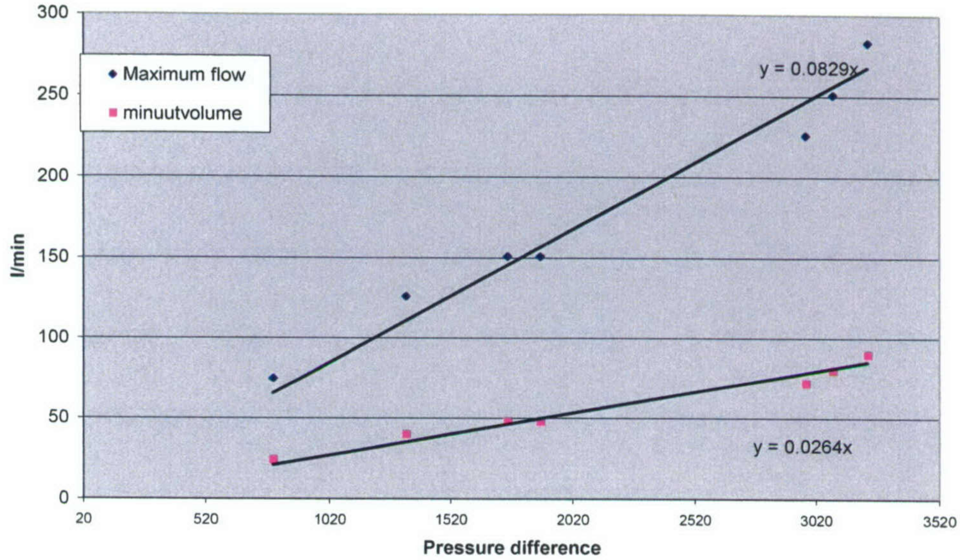

Figure A.1 Calibration lines for maximum and minute volume as measured for the old system. Data was generated on a dummy head using a breathing machine.

B Longmoore: Baseline

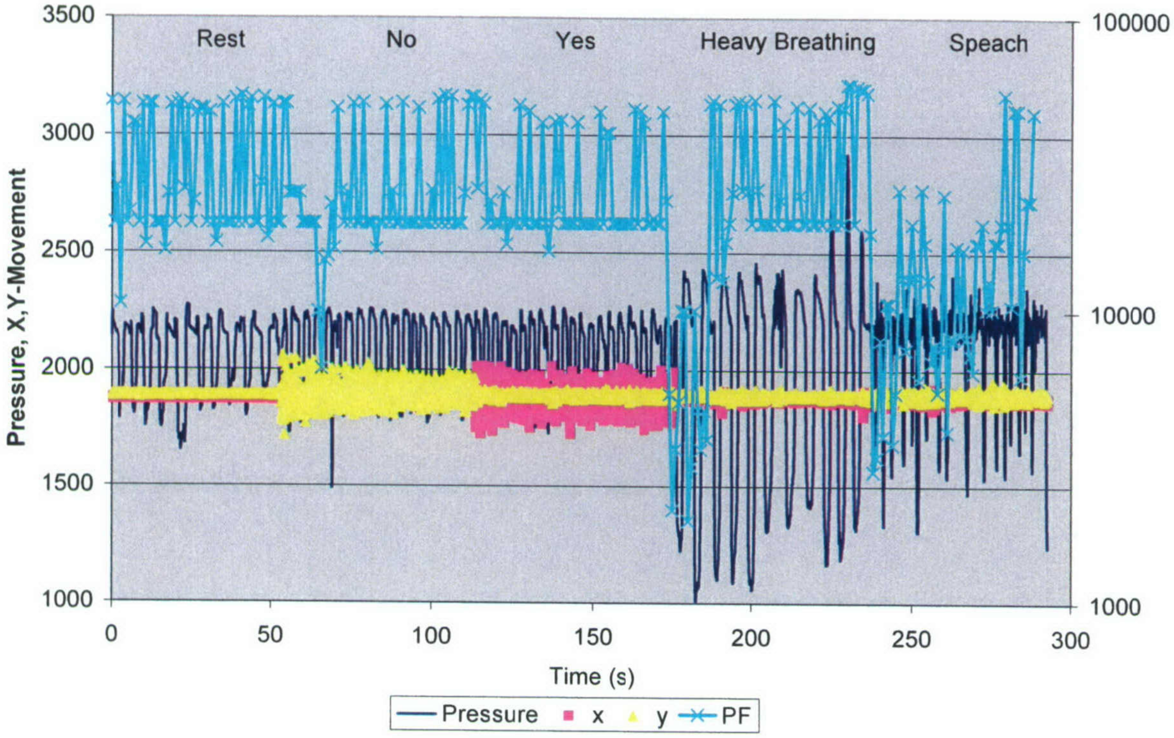

Figure B.1 Baseline recording on UK soldier Andy, left axis shows pressure and movement, right axis protection factor (light blue line).

C Long Moore: Run with shooting

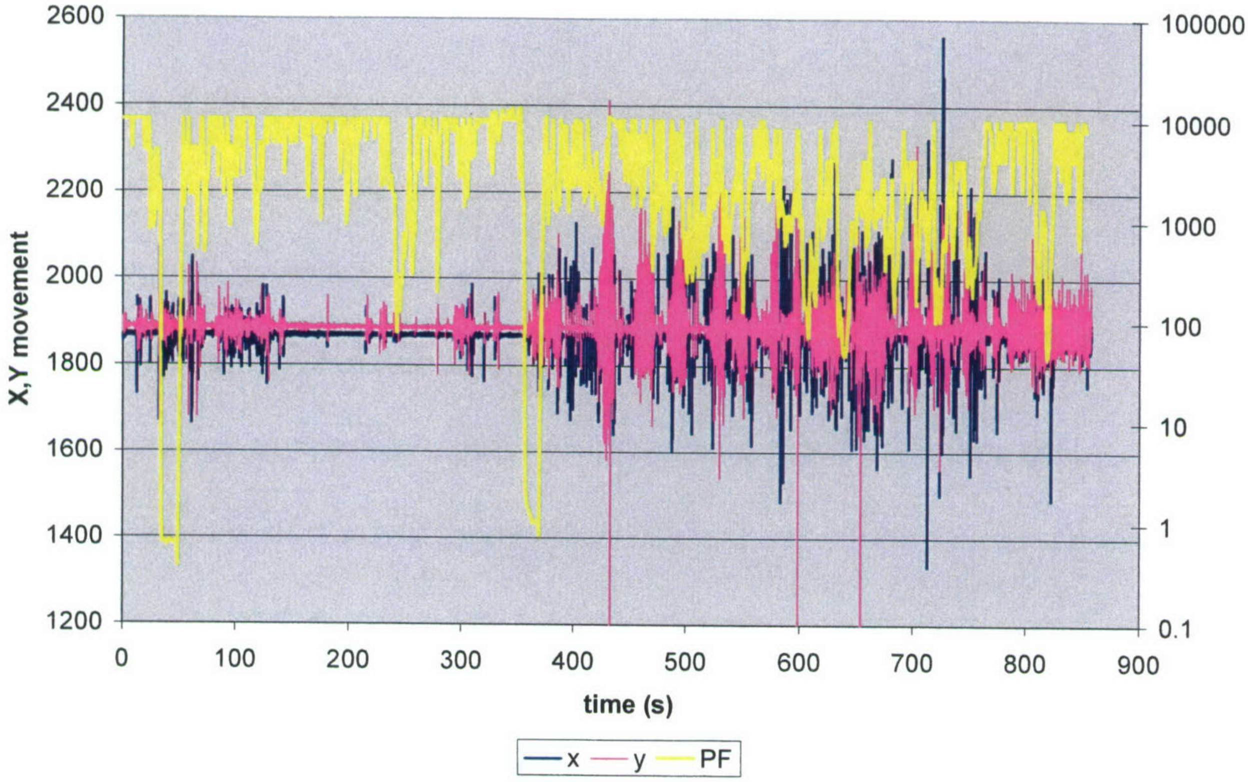

Figure C.1 Protection Factor and movement during a run of Angus with shooting, running and crawling.

D Long Moore: Second simulation run

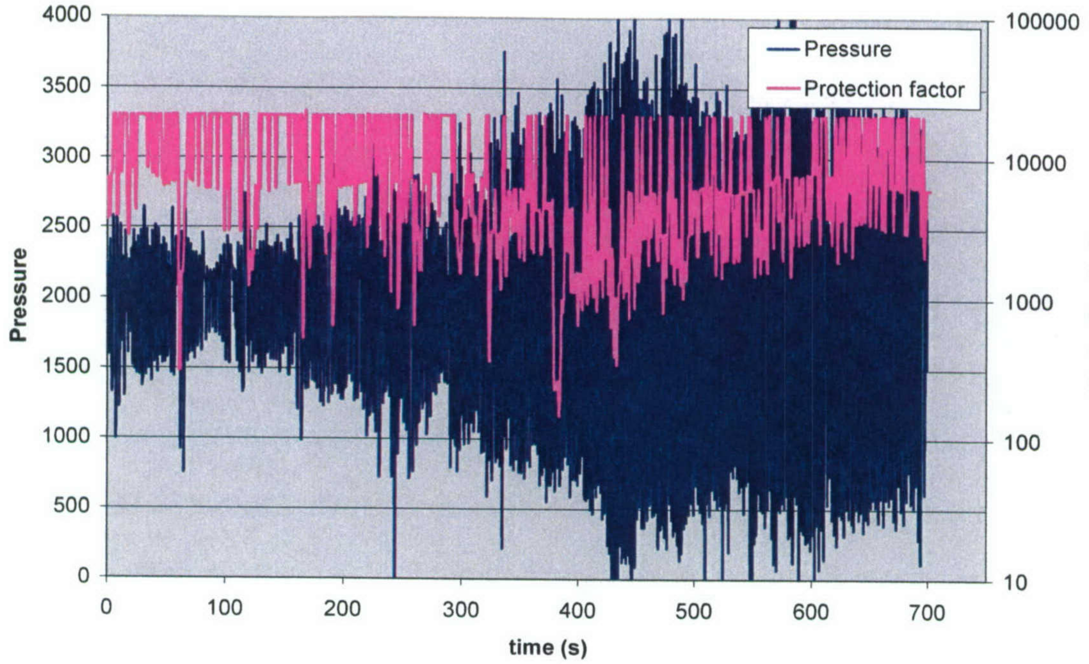

Figure D.1 Pressure and protection factor measured during the Long Moore trial with Angus. During this exercise the soldier simulated shooting and walked, kneeled and crawled through the field.

E Long Moor: Particles created by shooting

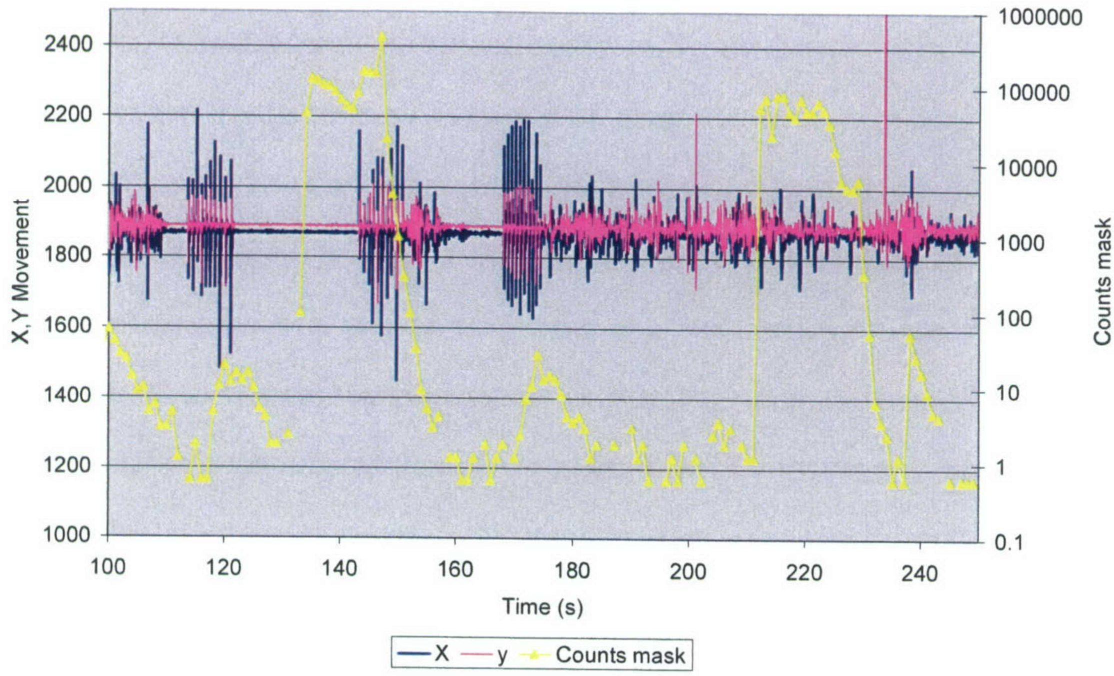

Figure E.1 Results of the Long Moore field trial. Clearly visible are the sharps x and y signals, which represents shots. Sometimes the ambient air particles concentration, which is monitored at some distance, increases after a shot but not always.

F Porton Down: concentration particles during digging

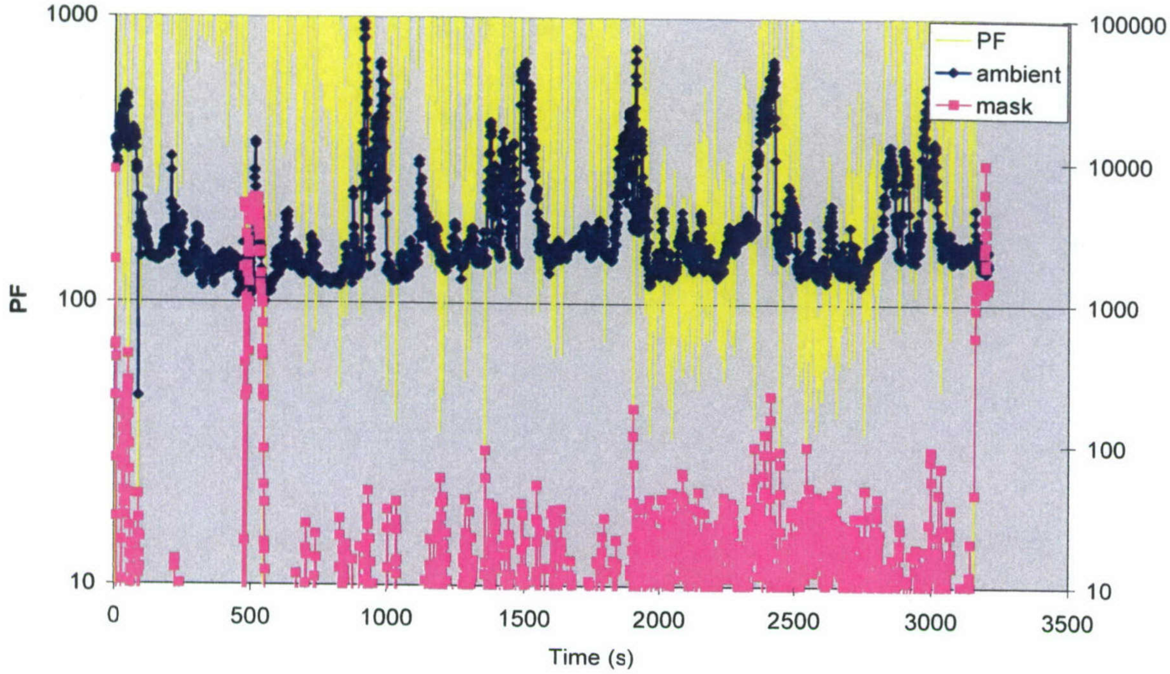

Figure F.1 Results of digging as measured with the new system.

G Porton Down: Digging (high average protection factor)

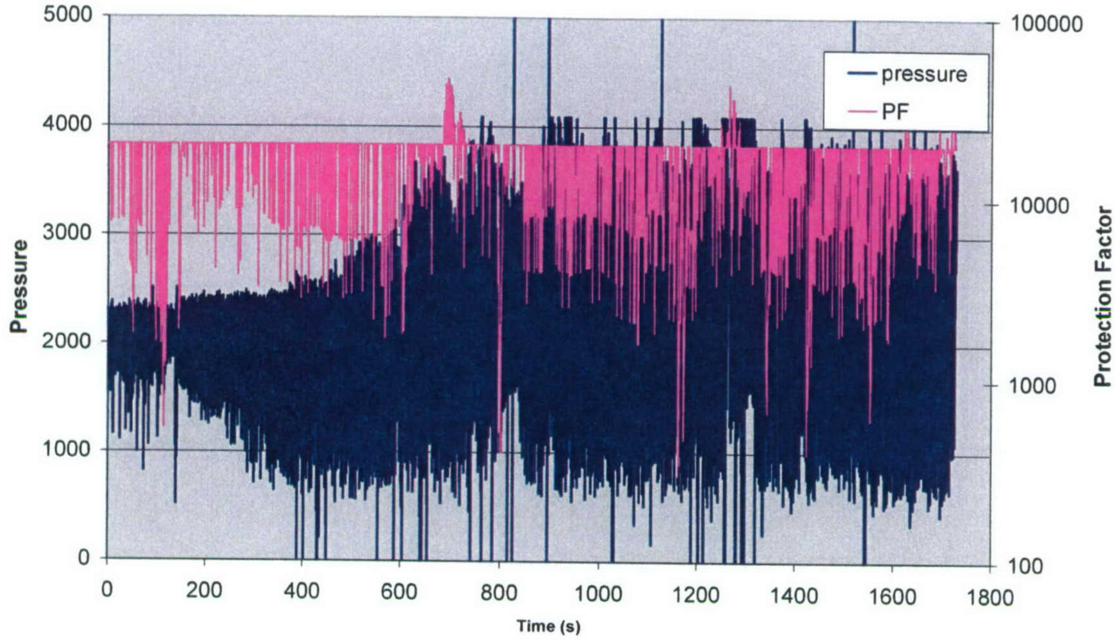

Figure G.1 Protection factor and pressure during the digging exercise. Results were obtained with Aage wearing the old system.

H Porton Down: Walking and Shooting

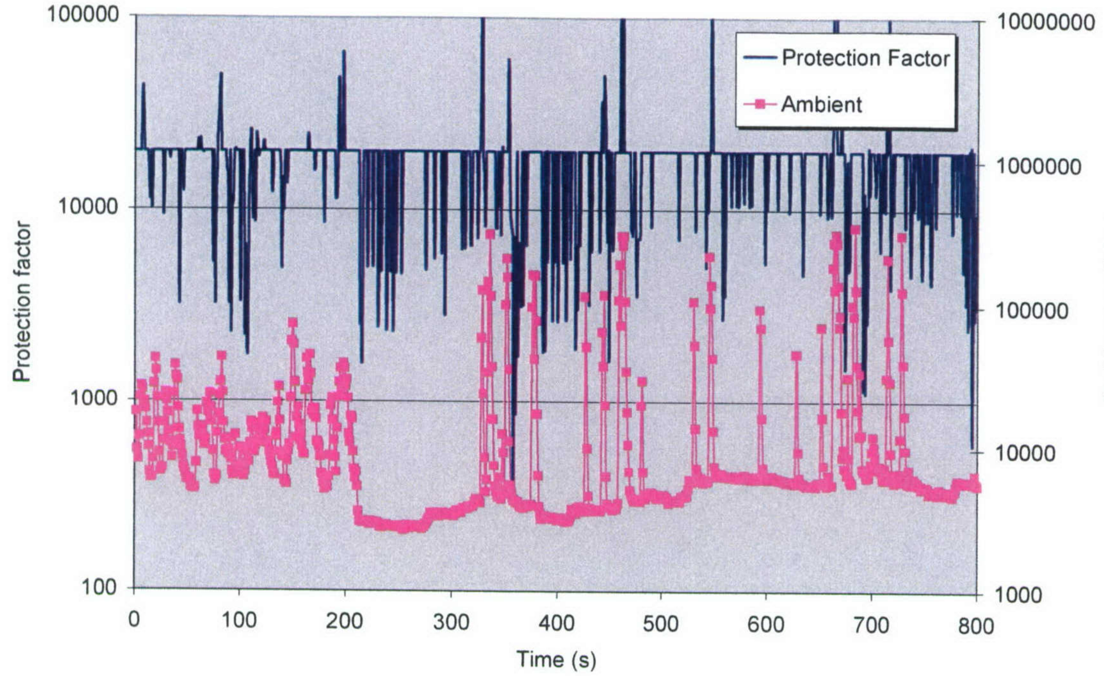

Figure H.1 Protection factor and ambient particles concentration measured during the Porton Down Field trial. Aage was walking and shooting. Shots are recognised by sharp increases in ambient air concentration.

I Porton Down: Games at NBC school

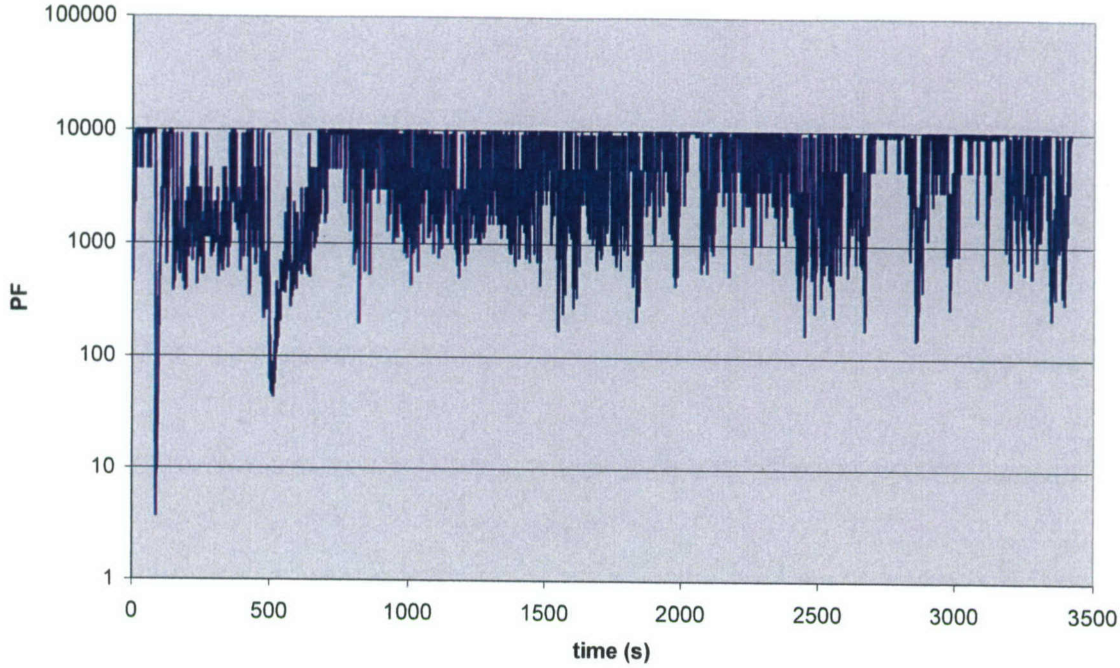

Figure I1 Protection factor measured during exercises at the NBC-School. Results were obtained with Aage wearing the new system.

J Leeuwarden: Standard Protocol

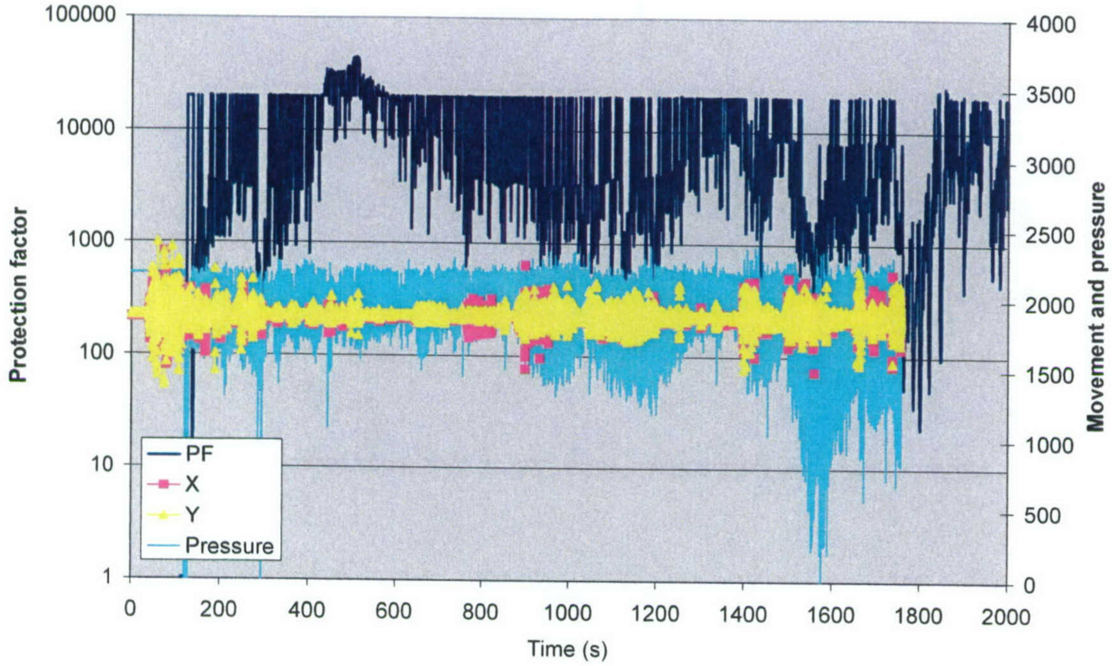

Figure J.1 Results of the standard protocol as measured during the Leeuwarden field trial with Gerard.

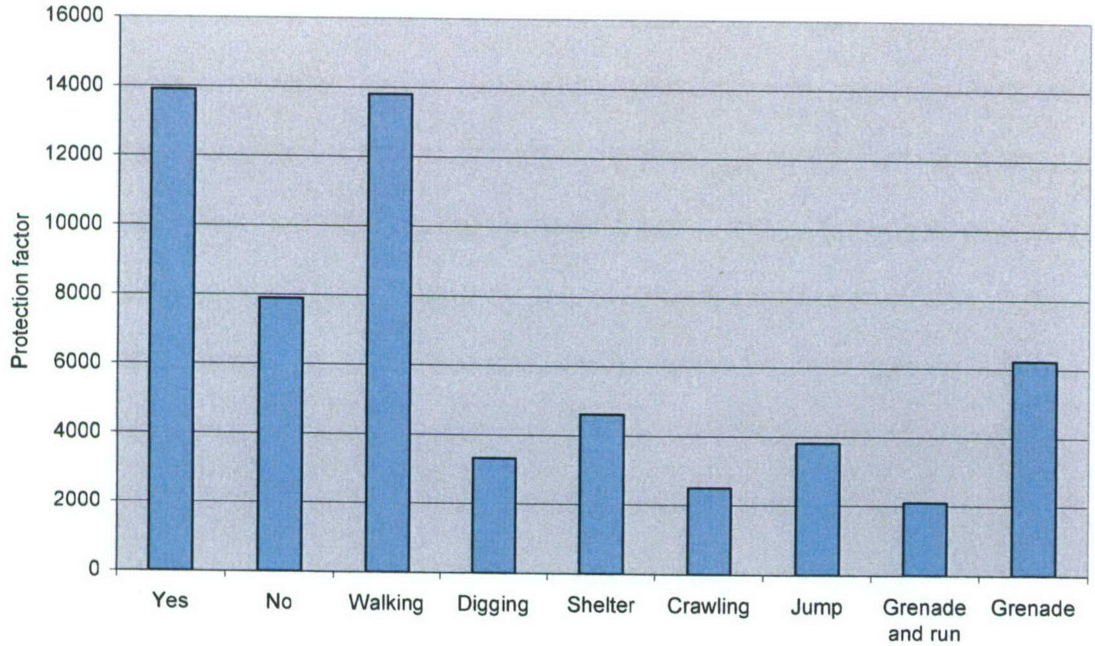

Figure J.2 Protection factor per event; data collected at the Leeuwarden field trial; standard protocol.

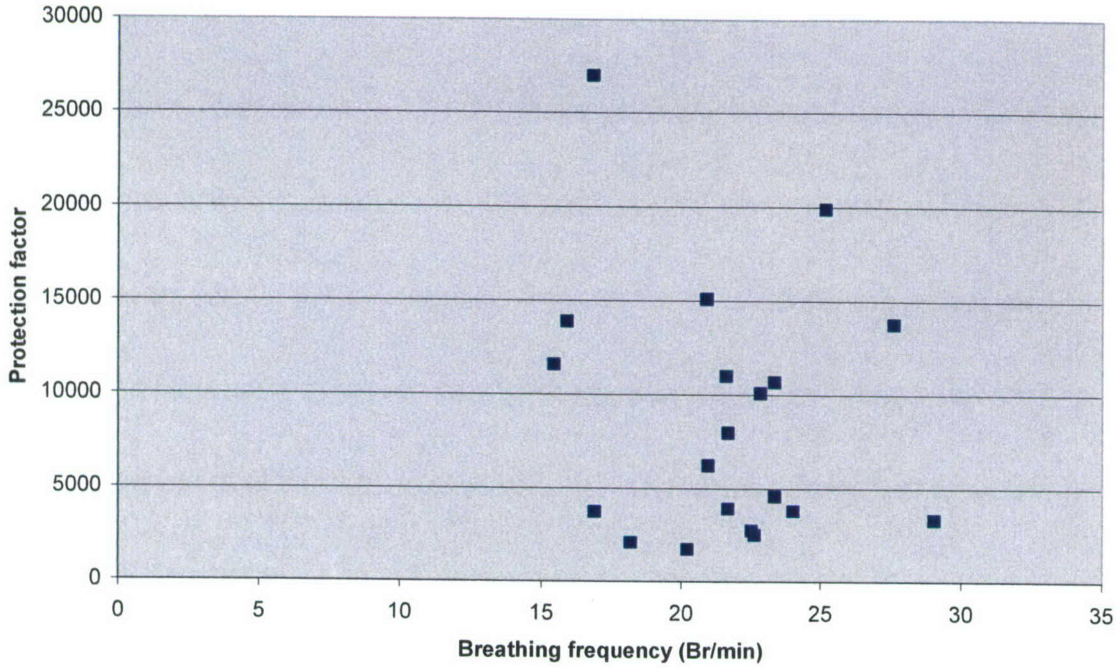

Figure J.3 Correlation graph of breathing frequency versus protection factor. Clearly no correlation is present between the two. Data is taken from data collected at the Leeuwarden field trial; standard protocol.

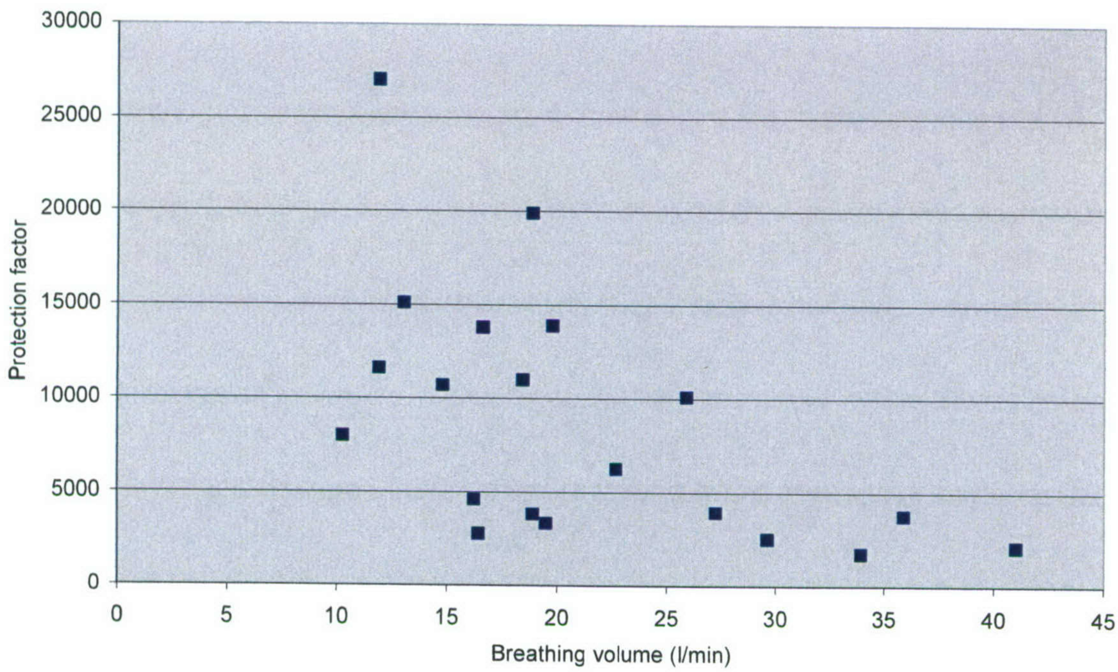

Figure J.4 Breathing volume versus protection factor. The breathing volume is the average taken one event. data collected at the Leeuwarden field trial; standard protocol. Clearly no correlation is present.

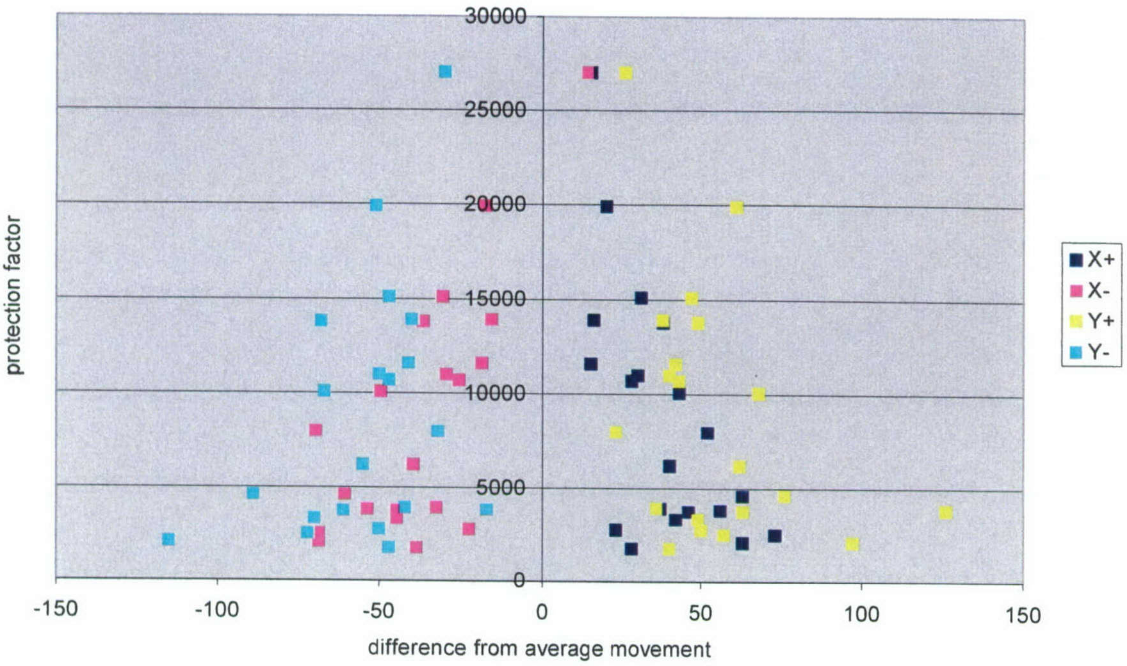

Figure J.5 Movement versus protection factor. The value shown is the average movement per event minus the overall movement. Data is taken from the Leeuwarden field trial; standard protocol.

K Leeuwarden: Shooting in a simulator

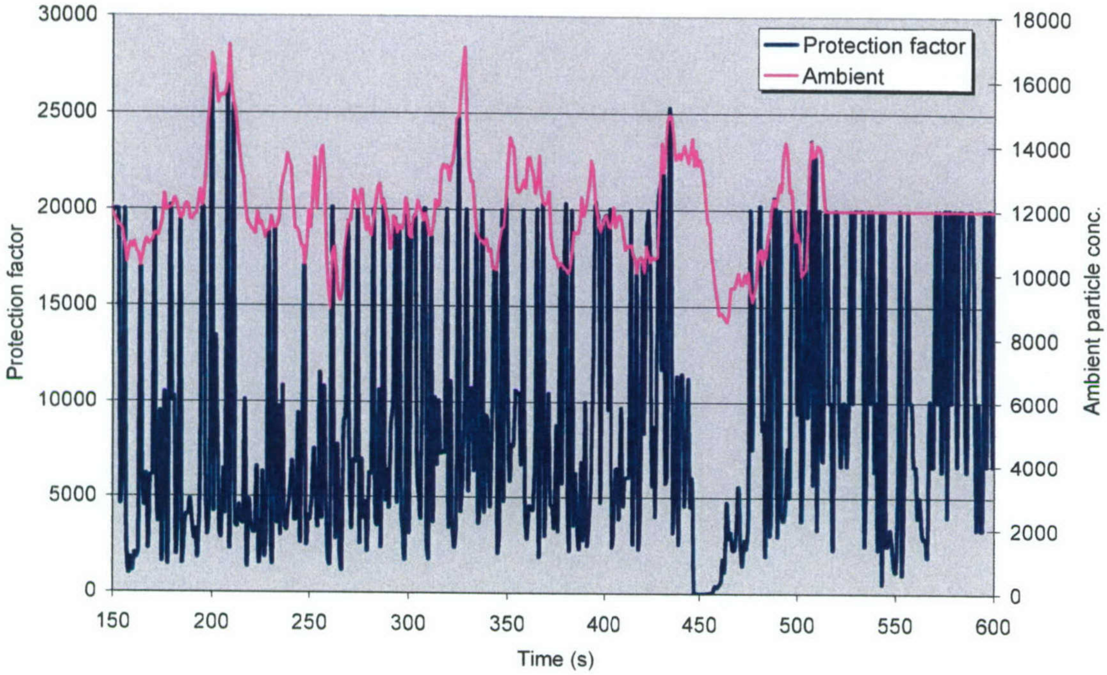

Figure K.1 Results generated during the Leeuwarden trial with Gerard as volunteer. Shown in this figure are the protection factor and the ambient air concentration. The average protection factor was approximately 400 during this exercise.

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15. ABSTRACT (MAXIMUM 200 WORDS (1044 BYTE))

In this report the results are described of three field trials. The purpose of these field trials was to measure the actual protection level of respirator during realistic NBC-exercises, like e.g. patrol and decontamination. Two field trials were conducted in the UK and one field trial in the Netherlands. In the latter special attention was given to the effect of recoil on the mask. The data show the protection offered by the Dutch FM12 respirator is not always adequate. No correlation between specific actions and reduction in protection factors were found.

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18. DISTRIBUTION AVAILABILITY STATEMENT		**17d. SECURITY CLASSIFICATION (OF TITLES**
Unlimited Distribution		Ongerubriceerd

ONGERUBRICEERD

Distributielijst V013 (BU-4)

Onderstaande instanties/personen ontvangen het managementuittreksel en de distributielijst van het rapport.

4 ex.	SC-WOO
8 ex.	HWO-KL
4 ex.	HWO-KLu
5 ex.	HWO-KM
4 ex.	HWO-CO
1 ex.	TNO Defensie en Veiligheid, Algemeen Directeur, ir. P.A.O.G. Korting
3 ex.	TNO Defensie en Veiligheid, Directie Directeur Operaties, ir. C. Eberwijn Directeur Kennis, prof. dr. P. Werkhoven Directeur Markt, G.D. Klein Baltink
1 ex.	TNO Defensie en Veiligheid, dr. D.W. Hoffmans
1 ex.	TNO Defensie en Veiligheid, accountdirector KL
1 ex.	TNO Defensie en Veiligheid, vestiging Den Haag, Manager Waarnemingssystemen (operaties), dr. M.W. Leeuw
1 ex	TNO Defensie en Veiligheid, vestiging Den Haag, Manager Beleidsstudies Operationele Analyse & Informatie Voorziening (operaties), drs. T. De Groot
1 ex	TNO Defensie en Veiligheid, vestiging Rijswijk, Manager Bescherming, Munitie en Wapens (operaties), ir. P.J.M. Elands
1 ex	TNO Defensie en Veiligheid, vestiging Soesterberg, Manager Gedrag, Training & Prestatie (operaties), drs. H.J. Vink
1 ex.	TNO Defensie en Veiligheid, vestiging Soesterberg , Communicatiemanager TNO Defensie en Veiligheid, P.M. van Bergem-Jansen
1 ex.	Lid Instituuts Advies Raad D&V BGen. prof. J.M.J. Bosch
1 ex.	Lid Instituuts Advies Raad D&V prof. dr. U.A. Th. Brinkman
1 ex.	KLTZ A.S. Baarda DS/CZ
1 ex.	Kol T. Ent Defensiestaf/HPL
1 ex.	Maj J.R. Swillens Defensiestaf/Plannen
1 ex.	Lkol ing. A.J.M. Pot Defensiestaf/IPS/MSA/NDO
1 ex.	D.M. van Weel HDAB

1 ex.	Drs. E.S.A. Brands DJZ/IJB
1 ex.	lkol A. Solkesz HDP/DPB
1 ex.	LTZT1 ir. J.W. Hartman KM/MARSTAF/OBS
1 ex.	Maj. R.F.M. Schröder Las/PBDL/OB
1 ex	Kapt. R. Brunsting Klu/PBDL/AOBB
1 ex	H.G.B. Reulink LBBKL/KPU-bedrijf

Onderstaande instanties/personen ontvangen een volledig exemplaar van het rapport.

1	SC-WOO, ir. P.J. Keuning
2	HWO-CO, mr. ir. P.A.G.M. Huijsmans
3	PHWO-CO, KLTZE E.H. Nieuwenhuis
4	Programmabegeleider V013, CDC/MGFB, A.S. de Koning
5	CDC/MGFB KLTZAR N.I. van Zaalen-Boelema Robertus
6/7	DMIVD, Kabinet
8	HJKC NBC,, Lkol C.A. Bourgondiën
9/12	LBBKL/KPU-bedrijf J.F. van Engelen
13/14	HJKC NBC, Maj M. Huisman
15	Programmaleider V013, dr. ir. M. S. Nieuwenhuizen
16	TNO Defensie en Veiligheid, vestiging Rijswijk, Manager BC Bescherming (operaties), ir. R.J.A. Kersten
17	TNO Defensie en Veiligheid, vestiging Rijswijk, Manager BC Bescherming (kennis), dr. R.W. Busker
18	TNO Defensie en Veiligheid, vestiging Rijswijk, Manager BC Bescherming (markt), ir. G.C. de Valk
19/20	TNO Defensie en Veiligheid, vestiging Rijswijk, Informatie- en Documentatiedienst
21/24	TNO Defensie en Veiligheid, vestiging Rijswijk, Business Unit BC Bescherming, dr. ir. M.J.G. Linders, dr. S. van der Gijp, L.A.W.M. Steenweg en ing. B. Nijboer
25	TNO Defensie en Veiligheid, vestiging Rijswijk, Marketing en Communicatie, digitale versie via Archief
26/28	Bibliotheek KMA