

Respirator Performance during Military Field Trials

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ABSTRACT

Uncertainty exists about the actual protection offered by military gas masks when used in the field. In civilian applications it is known that workplace protection factors (WPF) may deviate considerably in an unfavourable manner from nominal simulated workplace protection factors, determined under laboratory conditions. For this reason TNO-PML and DSTL (UK) developed a method for assessing the simulated workplace protection factor of military gas masks in the field situation, which are not directly comparable to WPFs. Characteristic for the method is that the test subject is capable of performing normal duty activities. The method includes the use of the TSI Portacount Model 8020 that measures the ratio of the outside to the inside ambient air dust concentrations. The use of an air pressure sensor inside the mask and of an accelerator sensor on the mask allows the monitoring of the breathing pattern and head movement effects. In this paper the results of a joint UK-Dutch field trial are presented. Special attention is given to the breathing patterns of soldiers and the corresponding protection levels of the Avon FM12-respirator during shooting, digging, decontamination and patrolling exercises.

Keywords: respirator, workplace protection factors, military

INTRODUCTION

Several simulated workplace protection factor studies have been conducted with the aim of establishing the actual level of protection of a worker in its working environment (Scanlan *et al.*, 2003; Cohen *et al.*, 2001). In contradiction to the situation regarding the civil workplace, the simulation of a relevant military work environment is more difficult to achieve. Not only the tasks of a soldier may vary between missions, but also the settings in which this mission takes place. Nevertheless, information is needed about the protection level of protective equipment during actual or simulated use. It is for this reason that Defence Science and Technology Laboratory (DSTL) and TNO-Prins Maurits Laboratory (TNO-PML) both developed systems to monitor the protection factor of soldiers during realistic field exercises. Both systems were used during joint field trials which were organized by DSTL and conducted in the United Kingdom. This paper describes only the results gained with both Dutch systems and the Dutch respirator.

METHODS

The field trials took place on shooting ranges near Long Moore in November 2002 and at Porton Down on June 2003. These shooting ranges consisted of flat terrain with a grass surface. Both ranges were fitted with automatic shooting targets. The trial was conducted with Dutch and UK soldiers, all experienced users of NBC-protective gear. In addition to the protective mask (FM12; AVON, United Kingdom) the protective gear consisted of a protective suit, gloves and boots. Note that the hood of the suit covered the face seal of the respirator. No fit test was conducted prior to the test program.

During the trials several relevant and realistic exercises were performed like:

- Shooting on position
- Patrol (with shooting)
- NBC reconnaissance
- Vehicle decontamination
- Digging foxhole
- Various physical exertion exercises

During the trials two different set-ups were used. Both systems used the TSI Portacount to count the number of ambient air particles inside and outside the mask. A schematic overview of system one is given in Figure 1.

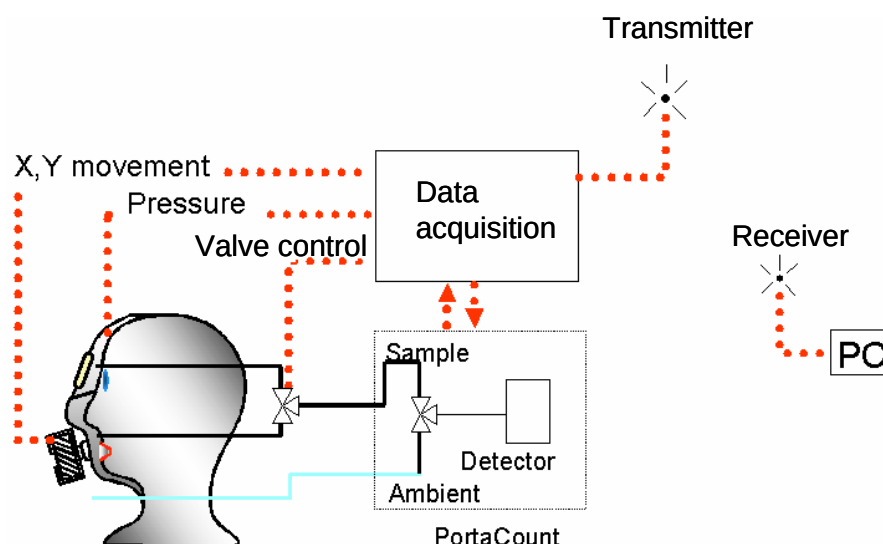


Figure 1. Schematic overview of system one for measuring the protection factor of respirators in the field. In contradiction to system two, in which the second Portacount measures the outside particles concentration near the mask, the additional Portacount is located near the PC. Data shown in this paper is based on measurement of particles inside the inner mask cap. The valve control was not used to switch to sampling ambient air nor in the eye-region.

The full-facepiece respirator was fitted with a nuclear, biological and chemical (NBC) canister which prevents ambient air particles to enter the mask through the filter. After a short transition-period, in which the number of particles in the mask reduces rapidly after donning, the particles counted inside the mask were particles that leaked through either the face seal or the outlet valve.

In order to monitor the breathing pattern, in system one, the full-facepiece respirator was fitted with a pressure sensor (AE-sensors XPC0.3C; Murata, Japan) which measures with a frequency of 18Hz. The pressure was correlated with breathing rates by measuring pressure on a dummy head fitted with a FM-12 Mask and appropriate canister. The pressure was registered as a function of a range of breathing flows generated with a breathing machine (Bacou, France). In addition to the pressure sensors, movement sensors (Murata ENC-05EB, Japan) were used, which were fitted on the "primary speech

module/front cover" of the mask. The movement sensors measured in two directions, x (horizontally) and y (vertically), both with a frequency of 18 Hz.

The Portacount was connected with the mask by the drinking facility. The inner tube of the drinking facility inside the mask was removed. Particles in the inner mask of the FM12 respirator were counted once per second in the count mode of the Portacount. Ambient air concentrations were sampled with a remote Portacount, which was at least a couple of meters removed from the soldier. During the exercises, the soldier could be as far as a 100 meter from the second Portacount.

The data of the Portacount, pressure sensor and movement sensors were combined in a home-made data-acquisition box and transmitted to a laptop computer. The laptop computer was fitted with an additional Portacount which measured the ambient air particles concentration.

System two was based on the use of two Portacounts; one Portacount was connected with the drinking facility and one Portacount was used to measure the ambient particle concentration near the mask. The particle counts of both Portacounts were stored locally on palm top computers on the wearer. System two was fitted with a video camera and recorder, fitted on the helmet of the system; no pressure or movement sensors were used. Both Portacounts, the Palmtop computers and the video-recorder was stored in a bag-back.

RESULTS

Figure 2 shows the average simulated workplace protection factor of five exercises. Each exercise represents a part of a military operation. Some of these exercises are described in more detail below. The data presented is generated with both systems used on two soldiers. Both soldiers were experienced in using their respirators. Still a large difference in simulated workplace protection factors between the two soldiers was observed.

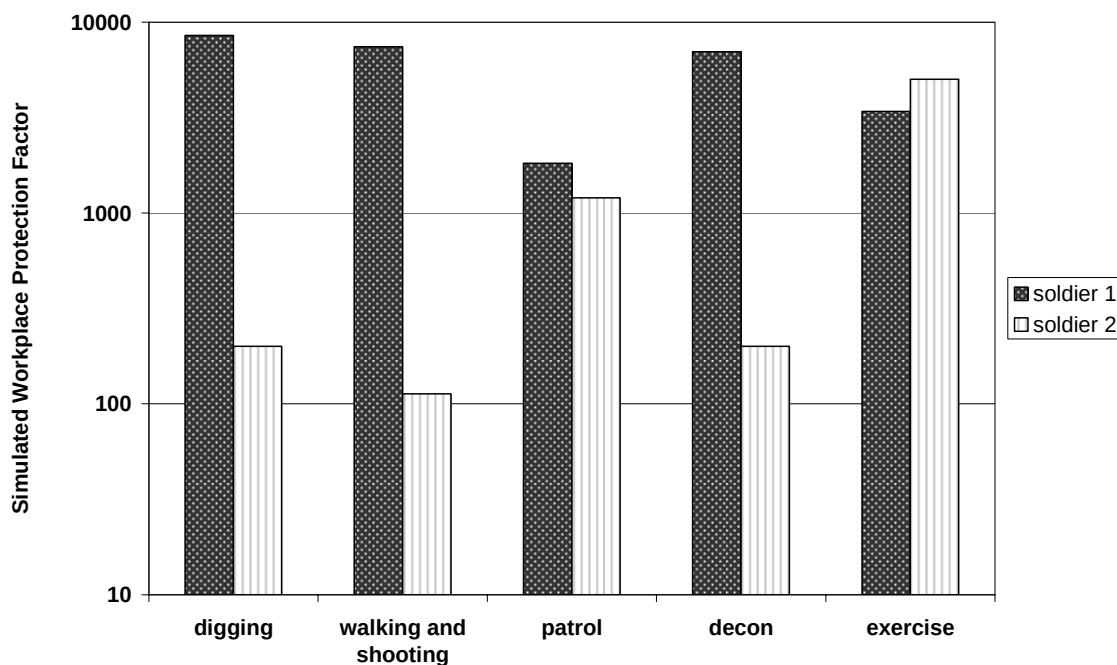


Figure 2. Average simulated workplace protection factors (log scale) for five exercises. Patrol and walking and shooting are the average of at least 4 runs.

During the length of the decontamination exercise (Figure 3) the average simulated workplace protection factor of both soldiers varied drastically also, namely between 200 and 6000. Although the average starting level of the simulated workplace protection factor for both soldiers differed, the pattern during the decontamination exercise was roughly the same. Periods of high simulated workplace protection factor were alternated with periods of low simulated workplace protection factors. When the decontamination solution was sprayed onto the surface of the vehicle artificially, locally the number of particles was increased, which for system one could lead to an artificially decrease in simulated workplace protection factor. After omitting this data still a high simulated workplace protection factor remained. No effect of speech was found.



Figure 3: Decontamination of a tank. Left, the second system with two Portacounts and the camera on the helmet; Right, scrubbing whilst wearing system one with movement and pressure sensor. During the exercise the tasks were switched. Filling and pressurizing the canteen was also part of the exercise. Both soldiers wore impermeable suits.

During the digging exercise both soldiers wore a permeable NBC-protective garment over their combat dress. This exercise was extremely hard, because of the unbreakable limestone layer 20 cm underneath the surface. During the second half of the exercise the simulated workplace protection factor of both soldiers dropped from approximately 4000 to 200. During the exercise the minute volume of the soldier wearing system one increased from 16 to 90 l/min, (Table I). However, also sweat could be a reason for the decrease in the simulated workplace protection factor. After the exercise the mask was filled with sweat. During the exercise the soldier was blowing bubbles of sweat escaping from the face seal indicating the combined effect of sweat and the breathing volume.

The patrol exercises consisted out of walking through the terrain, kneeling or lying down and frequently firing a rifle. The average simulated workplace protection factor as shown in Figure 2 is based on the average as measured with system two. Results of system one, regarding exercises in which firing took place were omitted because locally generated particles reduced the simulated workplace protection factor artificially. Note that in system two by measuring locally near the mask this problem is solved.

During one of the patrol scenarios both soldiers walked through rough terrain. After a couple of minutes they engaged the enemy and started firing. In the first part of the exercise, without shooting, the average simulated workplace protection factor for both soldiers measured with system two was 1880. During the second part of the scenario, in which the soldier walked, talked, kneeled and fired, the

simulated workplace protection factor dropped to 675. Again the drop in simulated workplace protection factor is a combination of movement, sweat and the recoil of the rifle. In the second half of the exercise during a short period in which no firing occurred, the simulated workplace protection factor was 320 indicating other effects than recoil of the rifle alone.

The effect of breathing volume on the simulated workplace protection factor is also clearly illustrated in Figure 4; a detailed example of the course of the simulated workplace protection factor, breathing volume and movement during one of the patrol exercises. In Figure 4 the results of two runs were combined. One run in which firing was simulated and therefore pressure could be recorded; and one exercise in which actual firing took place. Both runs were conducted only with a short time interval in between by the same soldier. Although the simulated workplace protection factor started out higher than 6000; during the exercise the simulated workplace protection factor dropped frequently below 1000 which led to an average simulated workplace protection factor of 3200.

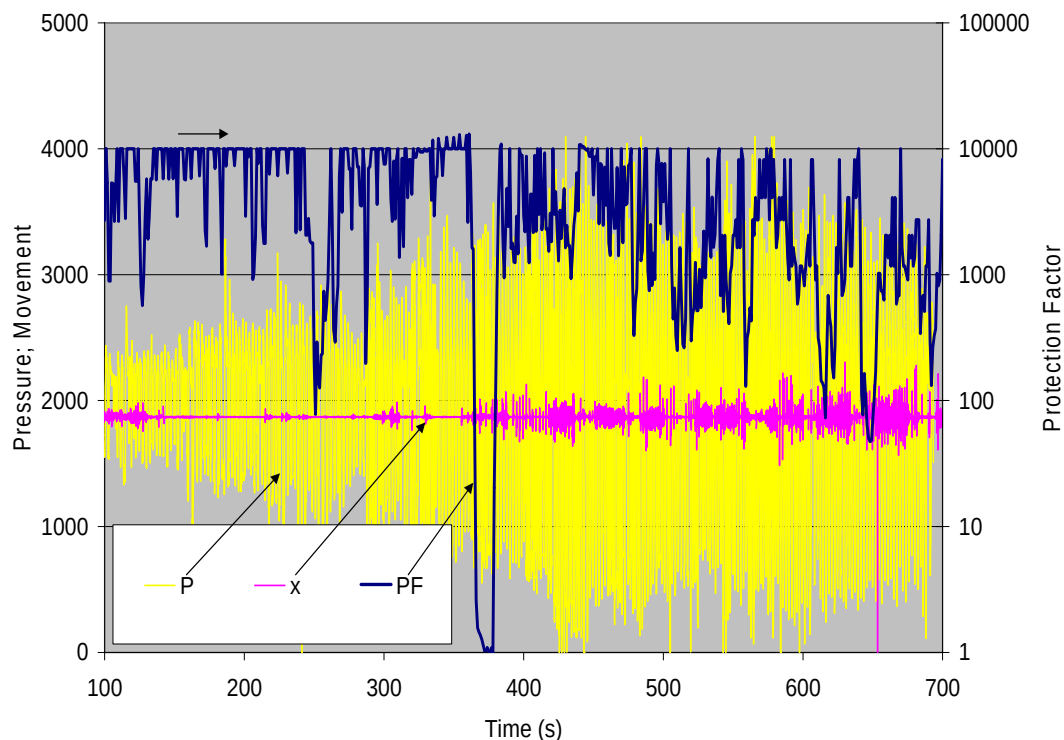


Figure 4: Patrol with shooting; Protection factor and X-movement data are combined with pressure data of a similar run without shooting. Note that monitoring pressure is not possible during firing. When protection factor drops to 1, ambient air was sampled as reference. Note that by definition a SWPF is 1 when $C_{\text{ambient}}/C_{\text{mask}}$ are the same ($\text{SWPF} = C_{\text{ambient}}/C_{\text{mask}}$). At maximum exertion the pressure difference during one breathing cycle corresponded to an average minute volume of 100l/min. For clarity only X-movement data is shown.

The exercise described in Figure 2 consisted out of various exertion games like e.g. a 100 meter sprint in a soccer game. The simulated workplace protection factors during these games were 5000 and 3400 for two soldiers. The breathing rate as a derivative of pressure measured during four of the exercises is shown in Table I.

Table I. Breathing Rates (The maximum and average flow during four exercises. Data presented are the average and maximum flow at the start of the exercise, the average of the exercise and the highest value during the exercise)

<i>Number</i>	<i>Exercise</i>		<i>Average Minute Volume (l/min)</i>	<i>Max Flow (l/min)</i>
1	Decontamination	Start	17	53
		Average	21	66
		Highest	40	124
2	Digging	Start	18	56
		Average	40	124
		Highest	90	282
3	Patrol (1)	Start	26	83
		Average	63	199
		Highest	100	315
4	Patrol (2)	Start	16	50
		Average	35	138
		Highest	53	166
NATO Standard	30, 50 or 80			

The data presented in the table above is based on the breathing rate of three persons; exercises 1 and 2 were conducted by the same soldier. Although the breathing capacity of each person differentiates, still these data show that during various exercises and hence also in actual use the maximum flow through the mask and filter can be higher than the flow used for testing. Note that the pressure sensors only measure with 18Hz; extremely short fluctuations in pressure and consequently extreme high breathing patterns might even be missed. In addition, leakage could also contribute in lower flows measured than actually occurred.

DISCUSSION

During a number of standard exercises e.g., running, crawling, jumping, attempts were made to find a direct correlation between the drop in simulated workplace protection factor and the breathing frequency, breathing volume and head movement. Although the correlation between (parts of) an exercise and the level of simulated workplace protection factor was present, the correlation between each individual factor could not be established. The contribution of the above mentioned factors can not be seen individually and it is likely that other factors like e.g. sweat and donning the mask also play an important role.

Taking 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 simulated workplace protection factors accurately with system one (Bierman *et al.*, 1991a, 1991b, 1991c). When shooting is part of the exercise, which raises the number of particles drastically, only system two can be used because 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 could be generated by the test and hence give rise to artificially lowering of the simulated workplace protection factor. Still the authors of the paper feel that the (trends in) simulated workplace protection factors shown in this paper are valid and reflect the actual workplace protection factor. Finally note that only face seal and outlet valve leakage is monitored with this method, filter breakthrough is not taken into account.

CONCLUSIONS

Various exercises, all representing relevant parts of a possible military mission, each have their effect on the protection offered by a respirator. Even with experienced mask users the protection offered by full face masks in the field, in some cases is insufficient for an adequate protection. Note that the requirement for military respirator is confidential and therefore can not be stated in this paper. Breathing rates, recoil of the rifle and sweat each contribute to a decrease of the protection factor.

During the trials average minute volumes up to 100 l/minute were found. The large breathing volume but also the severe movement and sweating indicate that the current standards for evaluation NBC-protective respirators need to be evaluated.

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