

COMPARISON OF PROTECTION FACTORS FOR SELECTED MEDICAL, INDUSTRIAL AND MILITARY MASKS

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ABSTRACT

Personal protection against infectious or toxic aerosols is a growing area of concern among many different occupational groups. Selection of appropriate respiratory protection should be based upon the level of risk present and the degree of protection afforded by the different types of protective masks available. In this study we have determined the relative protection factors for various commercial and military respiratory protective devices when challenged with a polydispersed submicron to micron sized particulate aerosol.

INTRODUCTION

The respiratory protection afforded by any particular type of protective respiratory equipment is dependant both upon the filtering ability of the mask itself as well as the degree of air leakage around the edges of the mask. A wide variety of protective respiratory equipment is available, each designed for a specific purpose. The common types of surgical mask are actually intended more for the protection of the patient rather than the wearer, for whom it provides little in the way of respiratory protection (Chen, 1992a; Davis, 1991; Weber, 1993). There is, however, a common misconception that surgical masks provide a significant degree of respiratory protection. Towards the other extreme is the military style gas mask intended to protect military personnel against lethal concentrations of chemical and biological warfare agents.

A variety of techniques for testing and evaluating the efficacy of protective respiratory equipment have been described in the literature. These techniques sometimes rely upon the use of an artificial head of some type to allow the sampling of a delivered aerosol through the protective mask (Chen, 1992 a, b, c; Johnson, 1994; Liu, 1984; Tuomi, 1985) and can also be done on personnel under working conditions (Myers, et al., 1995). At our facility we routinely conduct fit factor tests for staff

members who make use of the Canadian Military C4 gas mask. Fit factor tests determine the inward penetration around the face seal of the mask. Our fit factor test employs the drinking tube built into the C4 mask as a sampling port allowing us to measure ambient particle concentrations both inside and outside the mask. We employ a TSI Porta-count device, while the individual is wearing the mask and performing a defined series of head movements and breathing exercises, to conduct the test. Using this information, a quantitative fit factor is calculated. It is important to note that while this study makes use of a fit factor test for military respirators, for the purposes of comparison to all classes of respirators in this study we will refer to the overarching term of "protection factor," which encompasses both the inward penetration around the face seal as well as inward leakage through the filter material.

While the C4 is an excellent mask, it may not be appropriate for use in all military scenarios. On several occasions over the years we have had inquiries from the military on whether surgical masks could be used in place of the C4 under certain circumstances. For example, the Canadian Forces are frequently involved in humanitarian and peace-keeping operations in which military personnel may be exposed to infectious aerosols (e.g., during disease outbreaks in refugee camps). Could protection from this risk be accomplished using a more conventional filtering facepiece? The only guidelines we are aware of for protection against infectious disease are those for *M. Tuberculosis* (TB) (MMWR 1994). NIOSH approved HEPA respirators are the only ones that can meet the guidelines for respiratory protection against TB. In this study we have adapted the fit test technique normally used for the C4 to test a variety of filtering facepieces and cartridge respirators. Our tests illustrate the protection factors available from the various types of filtering facepieces and cartridge respirators as well as the great variation in protection factors seen from person to person with the same type of respiratory protection. We feel that this

type of test allows a realistic assessment of the degree of protection offered by the different types of respiratory protective equipment.

These tests are not usually considered appropriate for use with non-HEPA filtering facepieces. However, we have found this to be a very useful technique to illustrate to military and other lay personnel why surgical masks and other non-HEPA masks are inappropriate for protection against infectious aerosols. In addition, since our methodology includes the measure of sub-micron particulates, this information is also relevant to protection against biological toxins and other toxic particulates.

MATERIALS AND METHODS

The protective respiratory equipment tested in this study included: 3M Non-toxic Particle Mask No. 8500; 3M Dust and Mist respirator No. 8710; Technol Classic Surgical Mask No. 48200; Canadian C4 Military gas mask; Precept Comfort-cone Fluid resistant Surgical mask Fiberglass Free No. 65-3333; 3M Nuisance Level Acid Gas Respirator 9915; 3M Dust/Mist Respirator 9900; UVEX Better Breathing Respirator HEPA-Tech 3010; Dual cartridge Respirator half mask fitted with a HEPA filter cartridge, silicone (Lab Safety Supply) and 3M High Efficiency respirator with exhalation port No. 9970. Photos of the protective respiratory equipment are seen in Figures 1 and 2. Respiratory equipment is grouped as HEPA and non-HEPA.

For the initial testing, five DRES (Defence Research Establishment Suffield) volunteers served as test subjects for each type of protective respiratory equipment. Volunteers included males and females. The males were clean shaven. All volunteers were familiar with the test procedure as the staff are fit tested yearly with the Military C4 gas mask. Filtering facepieces that clearly had a poor fit (e.g., surgical masks) were also tested with the filtering facepiece taped onto the face (with surgical tape). Surgical tape is very porous and its use here was not intended to provide an air tight seal of the mask to the face. Its intent was eliminate the broad gaps seen between the mask and the face which provided very obvious routes for gross air leakage. This variation of the experiment demonstrated the relative amount of face seal leakage for these filtering facepieces. Filtering facepiece with a form fitting design and a good seal were not tested with the tape method. Following the initial tests, further

testing was done with the 3M No. 9970 mask in an additional 17 volunteers.

Mask testing was conducted using a Porta-Count device (TSI Inc., St. Paul, MN, USA). This device is normally used at DRES for testing the fit of the C4 mask by comparing particle counts (0.02 - 1 μm size range) in the ambient air C_o (augmented by the presence of a burning candle in the room) against those within the mask itself C_i . The ratio of these two concentrations (C_o/C_i) becomes the quantitative fit factor (QNFF) (Johnston, 1992). The concentration of particles are measured in units of particles per cm^3 . The measurement is taken while the individual being fitted wears the mask and completes a series of 6 exercises. The exercises are as follows: normal breathing, deep breathing, moving the head from side to side, moving the head up and down, reading a paragraph of text out loud (the "rainbow passage") (Fairbanks, 1960), and normal breathing. The duration of each exercise is 80 sec. In the case of the C4 mask, the drinking tube is used as a sampling port to sample the air within the mask. For the other respiratory protective equipment tested, a short length of Tygon™ tubing was inserted through a hole in the mask in the nose/mouth region and the hole sealed with GE RTV 108 Silicone Rubber Adhesive Sealant™ (GE Silicones Canada, Pickering, Ontario). The quantitative fit testing procedure is the same as that outlined by The Office of Health and Safety (OHS) in their respiratory protection program manual (OHS, 1997). In the context of this study the ratio of these two concentrations (C_o/C_i) will be referred to as the "protection factor."

Standard deviations of mask protection factors were determined using SigmaStat statistical software (Jandel Scientific, San Rafael, CA, USA). This program was also used to determine the statistical significance of the difference in protection factors between selected masks using the Mann Whitney Rank Sum test.

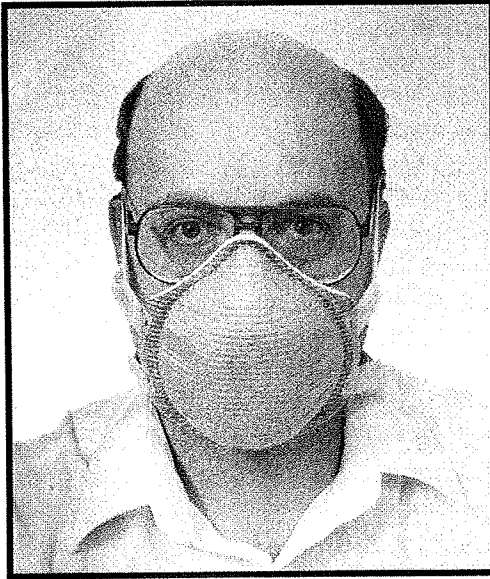
RESULTS

The results of tests conducted on non-HEPA style filtering facepieces are presented in Table 1 and the results from HEPA style filtering facepieces and cartridge respirators in Table 2.

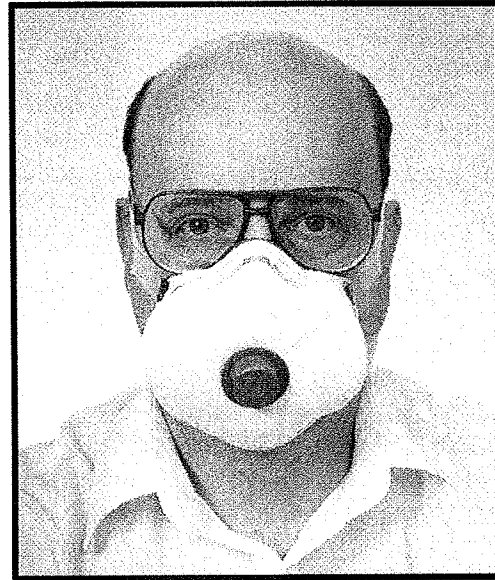
Table 3 is a summary of the results from additional testing done with the 3M Model 9970 filtering facepiece. Each of the 22 volunteers was tested with both medium and large size facepiece. Only

FIGURE 1

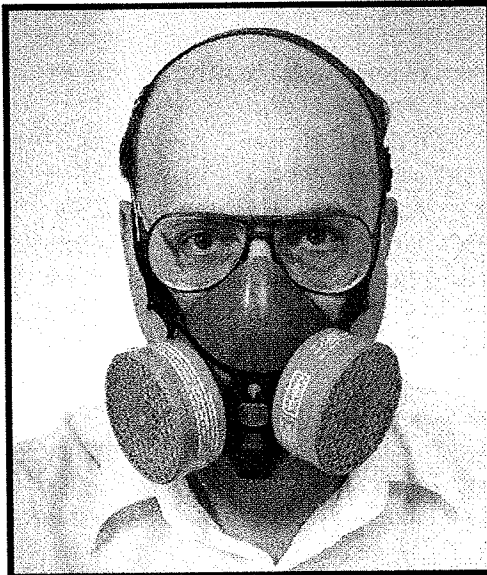
Photos showing the 4 types of HEPA style masks tested.



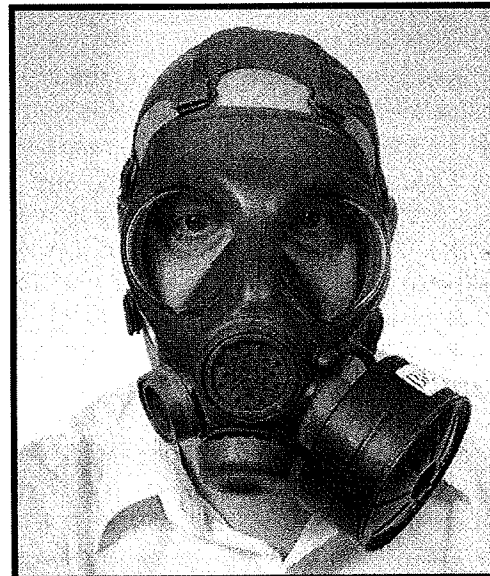
Uvex Better Breathing



3M No. 9970

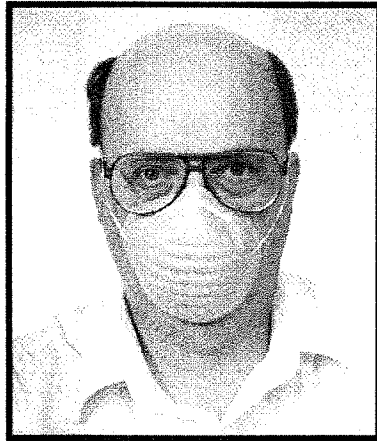


Dual Cartridge Respirator

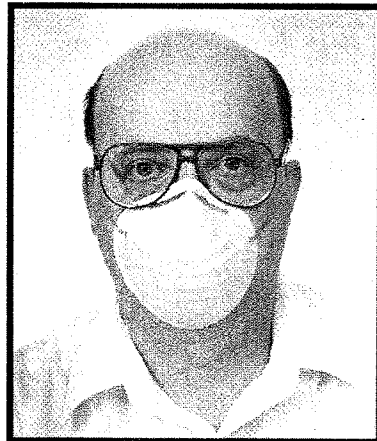


Canadian Military C4 Mask

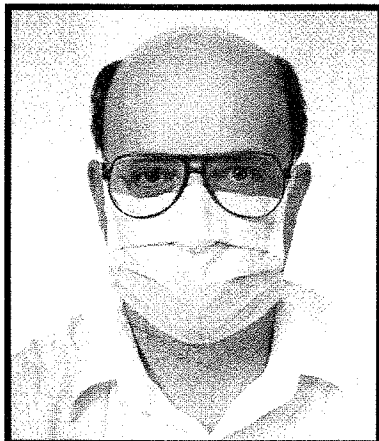
FIGURE 2
Photos showing the 6 types of non-HEPA masks tested.



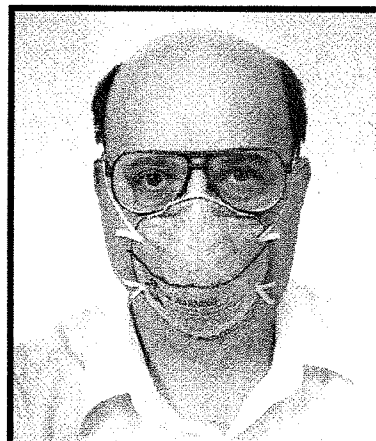
Precept Comfort Cone



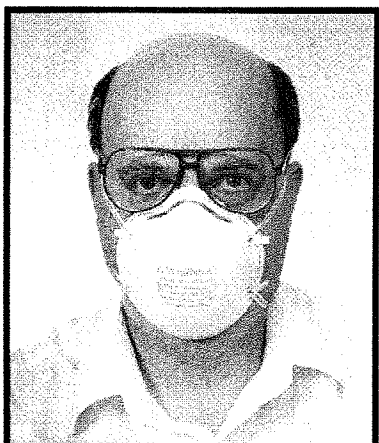
3m No. 8500



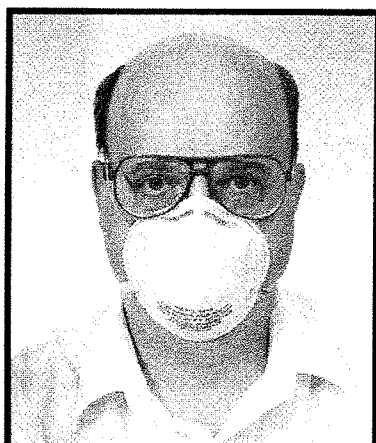
Technol Classic No. 48200



3M No. 9915



3M No. 9900



3M No. 8710

COMPARISON OF PROTECTION FACTORS

TABLE 1
Protection Factors for Non-HEPA masks

Mask	Edge seal	Volunteer					Mean ± S.D.
		1	2	3	4	5	
Precept Comfort Cone Fluid Resistant Surgical Mask No. 65-3333	normal	2.3	1.6	3.3	3.1	1.9	2.4 ± 0.7
	taped	2.8	1.6	3.2	3.2	2.7	2.7 ± 0.7
3M Non-Toxic Particle Mask No. 8500	normal	3.2	2.8	2.7	3.2	3	3 ± 0.2
	taped	3.8	3.8	3.3	3.1	3.5	3.5 ± 0.3
Tecnol Classic Surgical Mask No. 48200	normal	4.9	3.3	2.1	2.1	5.6	3.6 ± 1.6
	taped	9.3	4.4	4.8	5.3	7	6.2 ± 2.0
3M Nuisance Level Acid Gas Respirator No. 9915	normal	19	6.9	32	7.7	16	16.3 ± 10
3M Dust Mist Respirator No. 9900	normal	36	9.3	39	5	10	19.9 ± 16
	taped	46	9.3	73	8.3	12	29.7 ± 29
3M Dust and Mist Respirator No. 8710	normal	20	12	21	9.4	42	20.9 ± 13
	taped	31	24	25	27	43	30 ± 7.8

TABLE 2
Protection Factors for HEPA-style Masks

Mask	Size	Volunteer #					Mean ± S.D.
		1	2	3	4	5	
Uvex Better Breathing Respirators	Large	375	1110	158	1210	1170	804 ± 498
3M High Efficiency Respirator with exhalation port No. 9970	Medium	168	1540	26	211	2360	861 ± 1037
	Large	441	91	244	159	98	207 ± 144
Dual Cartridge Respirator Half mask, Silicone	Medium	578	3760	933	23600	427	5860 ± 10,000
Canadian Forces C4 Mask		21500	38500	22000	21500	14200	23540 ± 8970

TABLE 3
Summary of Protection Factors for 3M No. 9970

Mask Size	# Volunteers	Protection Factors
Medium	15	Range: 44 to 2360 Mean: 451
Large	7	Range: 29-609 Mean: 257

data from the better fitting facepiece is included in this table. Fifteen of the volunteers had a better fit with the medium size and the remaining 7 had a better fit with the large size filtering facepiece.

DISCUSSION

There are no guidelines in terms of respirator selection for protection against infectious agents in general. There are, however, guidelines on respiratory protection against one infectious agent, TB. The performance criteria for personal respirators used to protect against TB include (among other criteria) the ability to filter out particles 1 μm in size. The only respirators which meet these criteria are NIOSH approved HEPA respirators, including the 3M and UVEX models examined here. Infectious droplet nuclei are in the 1 to 5 μm size range, and the HEPA respirators which protect against TB will filter out droplet nuclei containing other microorganisms just as well. There is a common misconception that surgical masks and other non-HEPA dust/mist masks will provide protection against infectious aerosols.

It is clear from the results that there is considerable variation in the protection factor of the different types of respiratory equipment. There are 2 mechanisms by which the respiratory equipment offers protection against aerosol: 1) filtration and 2) face seal. Filtration may be achieved by the proper use of a high efficiency particulate filter. On the other hand, face seal may only be achieved by proper design of the facepiece and how well the facepiece fits an individual face. Head and face movement by the individual wearing the facepiece (e.g., Breathing and talking which involve muscles around the nose, lip, mouth and upper neck) can create a "bellows effect"—a mechanism by which aerosol particles may be sucked inside the facepiece. The common types of non-HEPA masks offer very little in the way of respiratory protection to the user (Table 1) as compared to the HEPA-style masks as a result of both inadequate filtration and face seal. There were no significant differences in protection factors among the two surgical masks and the 3M non-toxic particle mask.

The industrial non-HEPA facepieces provided significantly higher protection factors than surgical masks ($p=0.008$), however the protection factors seen were not sufficient to provide real protection against aerosolized infectious materials, nor were they designed for such protection.

It should also be noted that TSI Inc. has stated in one of its Application Notes (ITI 019 Revised 9/96) that Dust Mist and Dust Mist Fume disposable facepieces cannot be fit tested using this technique. What we have illustrated here with these non-HEPA masks is not a "fit factor" (i.e., reflecting only face seal leakage) but rather a "protection factor" combining both the face seal leakage and the filtration capability of the facepiece.

The commercially available HEPA style facepieces provide respiratory protection that is far in excess of the non-HEPA facepieces. In all cases the protection factors were significantly greater ($p=0.008$) than the 3M industrial non-HEPA masks (3M Nos. 8710, 9900, 9915). The actual degree of protection that would be obtained by an individual wearing a HEPA facepiece is dependant upon the faceseal. As can be seen from the data in Tables 1, 2, and 3 there is a considerable range in protection factors between individuals wearing the same type of facepiece, even if the volunteer wore the same type of facepiece but of different size. In general, individuals concerned with protection against infectious or toxic materials would be better served by considering the use of the HEPA style facepiece in preference to the non-HEPA styles. However, given the great variation in protection factors seen between individuals we would also caution that conducting a fit test on each individual will be important.

The Canadian military C4 mask was designed to protect military personnel against chemical and biological warfare agents. The protection factors for this mask are very high, as noted in Table 2. Although the Canadian military must be prepared to deal with the threat of biological warfare, as in the 1991 Gulf War, many of its missions deal with an infectious aerosol hazard of a different nature.

Canada is frequently called upon to participate in United Nations peacekeeping and other contingency operations of a humanitarian nature. These operations may call upon military personnel to deal with refugees and other civilians in parts of the world where the endemic disease threats are the same as would be faced in biological warfare. Military operations in these situations could include activities such as handling, or exposure to, patients with unknown infectious diseases and biological wastes as well as sanitizing buildings suspected of harbouring endemic threat agents. In such situations the C4 mask may be inappropriate because of the unnecessary operational performance liability.

ties, logistical burden and cost. In addition, in situations where the Canadian military must deal with civilians, the visual impact of a C4 mask on the civilians must be taken into consideration. Civilians might perceive the mask as frightening and/or threatening and this perception could interfere in the process of carrying out a peacekeeping or humanitarian mission.

SUMMARY

The authors have made a recommendation to the Canadian military that, in certain circumstances, a HEPA style of filtering facepiece is acceptable for use where there is a risk of aerosol exposure to infection in a non-biological warfare scenario. The 3M High Efficiency Respirator No. 9970 (with exhalation port) would be suitable for Canadian military operations where there is a risk of exposure to infectious aerosols. The facepiece provides a reasonable and appropriate degree of protection (far greater than conventional surgical masks), is comfortable to wear, compatible with most types of eyeglasses, and is generally similar in appearance to a surgical mask (i.e., non-threatening to most people). The 3M No. 9970 suffers from one possible drawback. It contains a natural latex rubber to which some individuals may be allergic (as was the case with one of our 22 volunteers, resulting in a skin rash).

An alternate choice is the Uvex Better Breathing Respirator. It provides the same degree of protection but does not contain any natural latex, eliminating the problems of skin allergies. The lack of an exhalation port made the mask slightly less comfortable to wear and the height of the nose on this mask could interfere with some types of eyeglasses.

The selection of appropriate respiratory protection is an important decision and the recommendation we have made to the Canadian military are not likely to be applicable to all situations, nor have we examined all the masks commercially available. Both the 3M9970 and the UVEX products are commercially marketed as "HEPA Respirators for TB Compliance" meeting OSHA requirements as outlined in 29CFR1910.134 and CDC Guidelines on

TB. In the absence of general guidelines on respiratory protection against infectious diseases we feel this is an appropriate alternate.

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