Respiratory protection for Canadian Armed Forces members with headdress and/or beards: Powered air purifying respirators for interim use in CBRN training

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ABSTRACT

Background: The Canadian Department of National Defence (DND) and the Canadian Armed Forces (CAF) are in the process of developing inclusive solutions for chemical-biological-radiological-nuclear (CBRN) respiratory protection for CAF users. The ultimate goal is to provide a variety of low-burden CBRN respiratory protection options for operational use for all wearers, including those with facial hair and/or headdress, as well as other individuals with hard to fit faces in the context of fit testing.
Methods: In this study, the option of providing the in-service C4 and C5 CBRN respirators in a powered air form was investigated for their ability to provide adequate protection in both training and operational contexts, and for training procedures to be suitably adapted and implemented. Their performance was compared to existing requirements for the C5 respirator with regards to their ability to remove airborne contaminants via filtration, and for wearers with beards and/or headdresses, their fit factor in powered air mode, their protection factor in use via simulated workplace protection factor (SWPF) measurements, and their use in a tear gas hut for training.
Results: The flow rate through each of the two C8 filters in the powered air configuration was less than the 50 L/min at which the filters were specified and tested for approval, while the flow rates of the other two filter configurations investigated were similar to the C8. All were demonstrated suitable for use in the study and the C8's filtration performance in the powered air (PA) configuration would be appropriate for operational use. When fit factors were measured in the PA configuration, all individuals tested achieved a value greater than 10,000. Similarly, in SWPF all individuals obtained overall protection factors of greater than 10,000. Finally, in a training activity in the tear gas hut, all individuals were able to perform the training drills successfully without exhibiting effects from the tear gas.
Conclusion: The C4 or C5 PA configuration is suitable for use in CBRN training in the tear gas hut for individuals with beards and/or headdresses, and shows promise when used with the C8 canister for operational application in a CBRN environment, with further investigation needed to demonstrate meeting all of the operational requirements.

Keywords: chemical-biological-radiological-nuclear (CBRN) protection, beards, facial hair, headdress, respiratory protection, simulated workplace protection factor, CS tear gas, quantitative fit testing, powered air purifying respirator (PAPR).

INTRODUCTION

The Canadian Department of National Defence (DND) and the Canadian Armed Forces (CAF) are in the process of developing inclusive solutions for chemical-biological-radiological-nuclear (CBRN) respiratory protection for CAF users. The ultimate goal is to provide a variety of low-burden CBRN respiratory protection options for operational use. The ongoing C5B project aims initially to develop a non-powered accessory for use in training for wearers with facial hair and/or headdress, as well as other individuals with hard to fit faces in the context of fit testing, followed by addressing the development of solutions for operational use over the long term. However the CAF is motivated to provide interim solutions to all of the relevant CBRN respiratory protection needs as early as possible in order to facilitate recruiting and retention of diverse members.

An interim solution for CBRN training must protect during tear gas training, routinely used by the CAF for confirmation of CBRN training outcomes related to proper use of the protective equipment, and must be suitable for use during the remainder of field training activities, including potentially those using live chemical warfare agent. In this study, the option of providing the in-service C4 and C5 CBRN respirators in a powered air form was investigated for their ability to provide adequate protection, and for training procedures to be suitably adapted and implemented. The same configurations were considered for their utility for interim operational use.

BACKGROUND

The C5B project was initiated in 2020 by Defence Research and Development Canada, based on the CAF's desire to improve the inclusivity of the Forces' recruitment and training procedures. It is a current requirement that all CAF members who might have an immediate requirement to use such respirators be freshly shaven (preferably once daily), wear their hair appropriately, and wear no other interfering items that might break the seal or prevent the head harness from seating properly (CAF, 2013). However, initial work underway strives to solve the issues within CBRN training that may exclude certain members from full participation because they have difficulty achieving appropriate protection while wearing a negative-pressure, air-purifying CBRN respirator. The desire is ultimately to permit full freedom to participate in all CAF operations for members who wear a beard and/or headdress for faith reasons, as well as those who may have difficulty fitting the in-service CBRN C4 and C5 negative pressure air-purifying respirators (APRs) for a variety of other reasons. The project is developing requirements for such respiratory protection options for training and operations, examining how to potentially adapt existing tactics, techniques and procedures to the use of available respiratory protection options, and develop novel CBRN respiratory protection concepts for use in training and operations.

It is generally recognized that the wear of a beard and/or headdress can cause significant issues with the expected level of protection provided by a tight-fitting respirator (Canadian Standards Association, 2018), and civilian standards will generally prohibit their use by individuals who have significant interferences such as facial hair under the seal. This prohibition is usually implemented by preventing fit testing to select the correct size or model from being performed. For example, in Canada, CAN/CSA/Z94.4-18 (Canadian Standards Association, 2018) states in Clause 9.2.2:

> "Individuals shall present themselves for fit testing free from interference of hair where the respirator seals to the skin of the face or neck.
>
> Although the rate of hair growth varies among individuals, for many, this requires being clean-shaven within the previous 24 or preferably 12 h to ensure that hair neither infringes on the sealing surface of the respirator nor interferes with valve or respirator …"

Further, as addressed in the overall Z94.4 Clause 9.2, other interferences that may prevent the respirator from seating properly on the head and therefore compromising the seal must also be taken into consideration when fit testing the respirator, with a headdress falling into that category. Any individuals that cannot present themselves free from any interferences that do result in fitting problems are to be referred to the respiratory protection program administrator to find other solutions, which might include engineering solutions to reduce the hazard, issuing a loose-fitting respirator, or assignment to alternate duties.

While the CAF adheres to Canadian civilian norms where they are appropriate, it is apparent that there will be exceptions, and CBRN protection is generally one such exception. Canadian civilian standards would generally prohibit anyone from using a negative or positive pressure air-purifying respirator within an immediately dangerous to life or health (IDLH) environment; nevertheless, such is the norm for general-purpose CBRN protection in the military, although self-contained breathing apparatus may be used by a small number of specialized CBRN operators. Therefore, the investigation of the use of high-performance, off-the-shelf CBRN powered air-purifying respirators (PAPRs) was deemed appropriate in order to determine whether their use for individuals with beards and/or headdresses was a potential short-term solution to providing CBRN protection in certain scenarios of use.

The first goal of the study was to demonstrate whether adequate protection could be achieved for the affected wearers in the gas hut component of training (delivered in recruit and refresher training), and associated with that, the ability to modify the training procedures to conform with the differences in the respirator PAPR configuration. The second goal was to consider the appropriateness of the PAPR configuration for operational application, specifically with regard to inward leakage. The C4 and C5 respirators as procured by the CAF are specific in design for CAF requirements, and per the CAF's CBRN policies, individuals would be instructed to be clean-shaven (within 24 hours) when using CBRN respiratory protection; therefore, this study is intended to be an initial investigation into whether a deviation from that position is possible for select individuals based on the ability to provide adequate protection for the specified use environment.

Protection requirements in the gas hut

The hazard within the "gas" hut is an aerosol of CS ([(2-Chlorophenyl)methylidene]propanedinitrile). CS is a riot control agent that causes short-term eye and throat irritation (Centers for Disease Control and Prevention, 2018). The individual has successfully "passed through" the gas hut if they do not experience any tear gas symptoms while wearing full CBRN individual protective equipment (IPE) and performing required CBRN drills; it may take several attempts to achieve success in performing the drills properly. The CS aerosol is generated by vaporizing solid CS, that is contained within a capsule, by either dropping the intact capsule, or opening the capsule to drop the powder, onto a hot-plate; the aerosol condenses subsequently into a particle size distribution and concentration appropriate to demonstrate significant failures of protection. The canister adequately removes the aerosol at the particle sizes and concentrations used, and therefore failures resulting in observed effects will arise from inward leakage of the CS reaching the eyes or respiratory tract through facial seal leakage or if drills are improperly performed.

The intent of the training activities is not to demonstrate that the respirator provides adequate protection *per se*, as that is the function of the selection and fitting process prior to training. Rather, the training activities demonstrate that the wearer can successfully perform (i.e. without experiencing adverse effects from the CS aerosol) CBRN drills that may expose the wearer if improperly performed, such as a canister change, drinking, and immediate personal decontamination of the head area. Therefore, the numerical protection factor requirement, to be determined prior to testing the particular solution in the gas hut, is based on the protection provided by the respirator during the remainder of the activities that are performed during training, and not the specific CBRN drills that are being trained. Assurance that these drills can be successfully performed in the PAPR configuration must also be demonstrated. These remaining training activities outside the drills include some head and body motions, and running within the hut to induce some sweating and heavier breathing.

Therefore, for this study, the protection requirements for the gas hut were set based on knowing the highest possible CS aerosol concentration resulting from the standard gas hut CS generation and training procedures, over the course of a series of 5-10 minute exposures while performing specific training activities. This concentration was ratioed to the relevant effects concentration in order to determine the highest hazard ratio (HHR); a protection factor (PF) higher than this HHR value will prevent effects from being observed for the majority of wearers provided CBRN drills can be successfully trained and performed. It is expected that the required PF to prevent observable effects in the gas hut when training is successful will be lower than that required for operational use, as the CS exposure conditions are less severe than those for the various warfare agents that set the operational PF requirements. Therefore it is possible that a PAPR concept could be suitable for training use, either with CS alone or with limited use of chemical agent, but not for full operational use.

Protection requirements for operational use

The protection requirements for full operational use were set based on those for the C5 respirator with C8 canister, evaluated as performed during its procurement in 2017, since the intended use environment is the same. The requirements for the canister to remove various types of chemicals and aerosols is unchanged; however since the blower uses two canisters instead of one as worn in the APR configuration, the flow rate to meet the requirement is half the flow rate of the blower, rather than the value used of 50 L/min for the APR configuration. The protection delivered by the entire respirator due to inward leakage is determined in an aerosol environment using simulated workplace protection factor (SWPF) measurements while wearing full protective equipment ensembles, and performing a variety of field-relevant activities that imply a high work rate including sweating, a variety of motions, and possible interferences from other equipment such as helmets and weapons. Based on this, the baseline requirement for protection performance in use is for the majority of wearers to obtain an instantaneous protection factor of 10,000, the majority of the time, regardless of the field-relevant activity performed.

METHODS

Participants

All of the participants in the study were serving CAF members, either regular forces or reserve forces. Investigations were performed under approved human use protocols (Defence Research and Development Canada and Royal Military College of Canada ethics review boards). The majority of the participants were chosen as they represented wearers with headdresses and/or beards. All of the participants represented potential users of the equipment, including instructors who would deliver the relevant modified training activities. Each was trained specifically with the PPE under test and the procedures to be followed. Bearded wearers for reasons of faith typically had long, untrimmed beards, and might or might not have had additional headdress. Females had either short hair, or long hair that was held in a ponytail worn low on the head, or wore a hijab. Turbans, patkas, or hijabs were the wearer’s own and were worn as the wearer chose normally. Other bearded CAF wearers for non-faith reasons typically had trimmed beards.

Personal protective equipment (PPE)

The respirators under test (illustrated in Figure 1 and Figure 2) consisted of:

- in-service C4 CBRN respirator facepiece (Airboss Defense Group, Acton Vale QC) used with C7A canister (3M Canada, Brockville ON) or C8 canister (Airboss Defense Group);
- in-service C5 CBRN respirator (Airboss Defense Group) used with C8 canister; and
- C420 powered blower (Airboss Defense Group), used with either facepiece, and two of the canisters specified above to match the facepiece.

Unless otherwise noted, the participants in the study wore the remainder of the in-service CAF CBRN individual protective equipment normal for training (Figure 2), which included:

- either the Horizon One coverall or legacy chemical defence coverall (in either case a one-piece hooded liquid repellent, active carbon lined suit custom-built for the CAF);
- Chemical-Biological protective gloves and liners (Airboss Defense Group);

- CBRN overboots (Airboss Defense Group) (sometimes omitted as they have little effect on outcomes); and
- gas mask carrier, custom-built for the CAF; filled with various items used for training including spare canister(s).

This equipment was worn over top of in-service combat shirt and trousers and underclothing, socks, and combat boots. One individual used a CG634 troop helmet for operational testing. A drinking canteen that mated to the respirator's drinking connector was used in the gas hut for performing drinking drills. In Figure 2 in the left-hand image, the individual is wearing the C5 facepiece with the C420 blower and two C8 canisters over the legacy coverall, while in the centre image, the individual is wearing the same respirator over the Horizon One coverall. Neither is wearing CBRN overboots. In the right-hand image, the individual with beard and headdress is wearing the C4 facepiece with the C420 blower and two C8 canisters, over their combat clothing.

Figure 1. Left: C4 respirator in PAPR mode worn by individual with beard and headdress; right: C5 respirator with C8 canister worn by individual without a beard or headdress in normal, non-powered mode.

Quantitative fit testing (QNFT)

QNFT to obtain the wearer's fit factor (FF) was performed on every participant prior to further use of the respirator. QNFT was performed first with the blower turned off (non-powered or NP mode) and using the appropriate in-service CBRN canisters. It was then performed in the powered air (PA) configuration with a low pressure drop in-line filter (3M, Brockville) inserted in the blower hose in order to prevent blower-generated particles from interfering with the measurement, and using two high efficiency particulate filters (S-70013 HE Filter, Airboss Defense Group) on the blower unit, the combination of which had approximately the same pressure drop and resulting blower flow rate as the normal configuration. In some cases, QNFT was also performed with the wearer in the C5 alone. No additional PPE was worn for the QNFT fit factor measurement.

Figure 2. Personal protective equipment worn for testing; see text for explanation.

The procedures used were otherwise identical to those routinely performed by the CAF for fit testing, as follows. The initial size of face-piece to be attempted (extra-small, small, medium or large for the C4, or small, medium, large, or extra-large for the C5) is chosen using a sizing tool and procedure provided. The individual wears the respirator for 5 or more minutes and reports on comfort after performing a suitable movement routine; if comfort is unacceptable another size is tried, otherwise they proceed to fit testing. Fit testing is performed within an enclosure with a generated sodium chloride aerosol (TSI model 8026 particle generator) in the range of 40,000-60,000 particles/cm^3. The activity routine performed consists of one minute of normal breathing, one minute of turning head side-to-side while opening and closing the mouth, and one minute bending over at the waist at intervals. The TSI 8020M condensation nucleus counter with custom software is used for measuring concentration within the respirator ('mask' value) and outside the respirator ('ambient' value), and determining the fit factor for each activity and over the entire routine. After the routine, the individual is again queried on the comfort provided. If the fit factor exceeds the required value and comfort is acceptable, the size and model are issued for use; if not, the procedure is repeated with a different size or model of facepiece as needed.

A minimum fit factor of 10,000 obtained in PA mode was used as the desired passing criterion for subsequent use, although a lower value could have been acceptable depending on context. The limit of detection of the method is better than a fit factor of 40,000.

PAPR flow rate

The highest flow rate from the C420 PAPR was determined for each of the two canister configurations, and on three replicate blower units each with fresh batteries, by adapting the output from the blower hose to the input of a TSI 4045G flowmeter. The measurement was performed three times on each replicate blower. Flow rate was also checked when needed, to ensure it exceeded the minimum requirement, using the airflow indicator provided by the manufacturer. The value obtained when the blower was equipped with the two HE filters and with the low pressure drop filter in the blower line was also measured, to demonstrate that this configuration had about the same pressure drop as the normal canister configurations.

SWPF determination

To understand whether the PAPR configuration could potentially provide adequate protection in the PA mode to affected wearers, SWPF testing was performed using required specialized test procedures [1][2], on seven individuals: four of whom wore religious headgear (patka, turban, hijab), and six of whom were bearded. Five were tested using the gas hut activity routine (Table I) using the C5 PA respirator (2 patka+beard, 1 turban+beard, 1 beard, 1 hijab), and four using the C4 PA respirator (2 patka+beard, 1 turban+beard, 1 hijab), with the air filtered in the same manner as for QNFT. Additional PPE worn included the Horizon One suit, CB gloves, and filled mask carrier. One additional test was performed on a wearer with turban+beard, with an alternate more vigorous operational activity routine (Table II) that included two rounds of activities without troop helmet (between rest 2 and rest 4) and one round with troop helmet (rest 4 through rest 5).

The basic PF measurement procedures used are similar to those described above for QNFT, except for the following changes. The enclosure used is much larger and may contain specific equipment to be used to conduct the activities, as well as a dehumidifier to maintain the relative humidity below 60%. The ambient and mask concentrations are measured simultaneously by separate PortaCounts. One PortaCount is connected to the wearer to measure the mask concentration, and the results are transmitted in real-time via Bluetooth to the analysis computer. This PortaCount is either carried by the test coordinator or placed on a rolling stool (Figure 3). The test coordinator also instructs the wearer in the activities to be performed in each minute. Prior to the start of measurement, all relevant information is recorded, the PPE is donned by the wearer and inspected by a test coordinator for proper wear, and the wearer performs a 5 minute fast walking warmup to increase sweating and breathing rate. The PPE is inspected again at the end of the SWPF activity routine, and the wearer and test coordinator note any comments regarding the equipment or conduct of the test.

The limit of detection of the method is variable depending on the equipment being tested and the wearer; wearers generate measured particles from their lungs and skin at a concentration dependent on the activity rate, but with the blower on, those particles tend to be cleared out quite quickly. The method as used here will be sufficient to measure a PF of well better than 10,000. The PF is reported instantaneously and also over each minute of activity.

Figure 3. Wearer within the SWPF enclosure performing activities.

Table I. SWPF activity routine to simulate gas hut baseline activities; each activity is 1 minute duration, for a total of 15 minutes.

Rest, Normal breathing
Bend at waist (10x), normal breathing (NB)
Shake head side to side (10x)
Nod head up and down vigorously (10x), NB
Run on spot
Run on spot
Run on spot
Rest, Normal breathing
Bend at waist (10x), NB
Shake head side to side (10x)
Nod head up and down vigorously (10x), NB
Run on spot
Run on spot
Run on spot
Rest, Normal Breathing

Table II. SWPF activity routine to simulate operational activities; each activity is 1 minute duration, for a total of 26 minutes.

Rest 1, normal Breathing
Crawl, look up, left and right
Run on treadmill (8 km/h)
Rest 2, normal breathing
Step up, raise arm, step off, touch floor
Carry buckets
Lunge, look up and down, over shoulder
Look & facial expressions
Crawl, look up, left and right
Run on treadmill (8 km/h)
Rest 3, normal breathing
Step up, raise arm, step off, touch floor
Carry buckets
Lunge, look up and down, over shoulder
Look & facial expressions
Crawl, look up, left and right
Run on treadmill (8 km/h)
Adjust respirator if necessary, don troop helmet, rest
Rest 4, normal breathing
Step up, raise arm, step off, touch floor
Carry buckets
Lunge, look up and down, over shoulders
Look around and perform facial expressions
Crawl, look up, left and right
Run on treadmill (8km/h)
Remove troop helmet, rest

CS gas hut testing

In a separate activity, seven wearers with CAF regulation beards were passed through a CAF gas hut (Canadian Forces Base, Valcartier QC) in a typical recruit training activity, with appropriate modifications to the training procedures to take into account the addition of the blower and the consequent change in location and number of the filter canisters. None of the wearers had headgear or untrimmed beards as there were none available at the time of the study. All were fit tested in NP and PA mode the day before the gas hut exposure and all achieved a passing quantitative fit test in PA mode.

Gas hut testing was performed for each wearer 9 to 12 times in order to address any training issues with wearer technique on the CBRN drills, and to obtain repeated outcomes with the two respirator configurations.

The activities performed were as follows:

Add CS pellets to hot-plate obtain a challenge level of 1 pellet per 28 m^3 of gas hut volume.
Confirm dressing and equipment status.

Enter the gas Chamber.

1) Confidence exercises
    a) Confirm protection (present the CS pan to each user[1])
2) Run around the chamber (30 sec)
    a) Confirm protection (present the CS pan to each)
3) Run in place (30 sec)
    a) Confirm protection (present the CS pan to each user)
4) Jumping Jack (30 sec)
    a) Confirm protection (present the CS pan to each user)
5) Run in place (30 sec)
    a) Confirm protection (present the CS pan to each user)
6) Nod the head up and down 20 times
    a) Confirm protection (present the CS pan to each user)
7) Turn the head left to right 20 times
    a) Confirm protection (present the CS pan to each user)
8) Change canister
    a) Pull the blower unit forward
    b) Hold breath and close eyes
    c) Stop the blower unit
    d) Wait for blower unit to stop (approx. 3 sec)
    e) Change canister
    f) Repeat steps for the second canister
    g) Turn on the blower unit and reposition at backside
    h) Confirm protection (present the CS pan to each user)
9) Connect canteen and drink some water
10) Drink and spit water inside the mask.
    a) Confirm protection (present the CS pan to each user)
11) Bend over 15 times.
    a) Confirm protection (present the CS pan to each user)
12) Jump in place (30 sec).
    a) Confirm protection (present the CS pan to each user)

Exit the chamber.

Immediate personal decontamination activities were not tested as their use was under revision at the time, and would be essentially identical to those performed with the respirator alone.

Optical particle counting (AlphaSense OPC-N3 Optical Particle Counter) was performed in real time to determine the particle size distribution of CS in the gas hut over the course of the activity.

RESULTS AND DISCUSSION

PAPR flow rate

The flow rates measured from the PAPR blower units, with the 30” hose attached and two canisters installed, are summarized in Table III. The values reported are after about three minutes of stabilization after the unit was turned on and with the reading varying by at most 0.3 L/min. It can be seen that in no case does the flow rate exceed 100 L/min, meaning that individual canisters should not be seeing flow in excess of 50 L/min, the flow at which they were qualified in the procurement for adequate removal of contaminants. It can be concluded that using the canisters in the PA PAPR configuration will not result in

[1] The pan containing the CS pellets that are being used to generate the aerosol is removed from the heat and placed underneath each wearer’s face for 1 to 2 seconds, to provide confidence that the mask is still protecting against CS even after performing exercises and CBRN drills.

any increased risk of penetration of the canister for the wearer compared with the negative-pressure single-canister configuration, although the change-out timing requirements might be different. Therefore, it is the inward leakage (protection factor) of the respirator, potentially affected by the change in the quality of the face seal for these wearers, which will be the limiting factor in achieving sufficient protection comparable to their cohort without beards or headdress. The use of the either C8 or C7A canister would be appropriate for particulate removal in the CS tear gas hut. Of the two, only the C8 canister is fully characterized for vapour removal at 50 L/min, and therefore would be preferred for operational applications. The filter configuration used for the QNFT and SWPF measurements is shown to exhibit approximately the same flow rate as the C8 and C7A configurations meaning that its use will not affect protection factor outcomes due to a differing flow rate.

Table III. Flow rates (average and standard deviation of three replicate measurements, L/min) from three C420 PAPR blowers with three different canister types.

Canister type	PAPR#1	PAPR#2	PAPR#3
C8	92.2 ± 0.3	88.3 ± 0.3	88.5 ± 0.5
C7A	88.5 ± 0.4	85.7 ± 0.1	86.2 ± 0.6
HE + low pressure drop in-line in hose (one filter set)	87.9	86.9	88.0

CS aerosol concentration and particle size distribution, and calculation of required protection

For a CAF standard gas hut test, the theoretical maximum CS concentration that will be achieved in a well-mixed chamber is approximately 21 mg/m^3, assuming no losses (dispensing 1 CS capsule of 0.58 g per 28 m^3). The applicable exposure guideline is the AEGL-2 (Acute Exposure Guideline Level) (disabling) for 1 hour, which is 0.083 mg/m^3 (Committee on Acute Exposure Guideline Levels, 2014). This corresponds to a highest hazard ratio (HHR) of 250, i.e. the minimum protection factor that should be achieved at all times during the training activity for no effects to be observed for most individuals[2].

Optical particle counting results relating to the mass and number particle size distribution for the CS generated in the gas hut are provided in Table IV. These diameters are around an order of magnitude larger than the value for sodium chloride aerosol as used in QNFT and SWPF testing [count median aerodynamic particle diameter of 0.13 μm and geometric standard deviation 1.75 (Duncan 2021)], which makes the latter fit factor and SWPF results conservative relative to the gas hut CS exposure HHR requirement. Therefore, the HHR based on the theoretical maximum concentration of 250 was used conservatively for further work.

Table IV. CS particle size distribution obtained in gas hut trial; diameters in μm and geometric standard deviation in brackets.

Mass median optical diameter	Geometric mass mean optical diameter	Number median optical diameter	Geometric number mean optical diameter
12.9	14.5 (1.16)	1.08	1.35 (1.16)

[2] There may be brief periods of higher localized concentrations during their gas hut training activities when the pan generating CS aerosol is placed underneath the face of the soldier, however these are extremely short instances (between 1 to 2 seconds, occurring 11 times over the duration of the activities), while the AEGL-2 level for CS is measured for an exposure of one hour.

QNFT and SWPF testing

The quantitative fit test fit factors are shown in Table V for the various respirator and wearer configurations investigated.

In every case evaluated, a QNFT in powered air mode yielded a fit factor over 10,000, whereas only the control participant (i.e. individual with no facial hair and headdress) was able to achieve an adequate fit for the C5 alone or in NP mode.[3] Similarly all individuals that were SWPF tested in PA mode for the C4 or C5 achieved an overall SWPF result greater than 10,000 (Figure 4 and Figure 5)[4], more than adequate to protect in the gas hut which requires, worst case, a demonstrated SWPF exceeding 250 per the discussion above.

The individual instantaneous PF values did drop below 10,000 in some cases on the second round of running on the spot. This could have been a real degradation due to heavier breathing and sweating, but could also be in part artifactual due to e.g. greater generation of background particles (Canadian Standards Association 2011) from the individual participants' lungs as they tire and therefore breathe harder (Johnson and Morawska 2009), or particulates shedding off of the beard during vigorous activities[5]. Such an effect could be teased out by using a higher concentration of generated aerosol, which would require an oil-based aerosol, as salt cannot be generated at concentrations much greater than those used here. Nevertheless, all participants achieved an overall SWPF of 10,000 for the routine used, demonstrating that this respirator configuration would provide more than adequate protection for use in the gas hut by affected wearers.

One participant with a beard and turban was assessed in the C4-PA respirator (Figure 6) using the activity routine that had been developed for assessment of general operational protection during the C5 procurement. Again, for the most part, the protection stayed well above the 10,000 mark, with occasional dips below during the running activity, as were observed during the gas hut routine above, and yielding an overall protection above 10,000 for the entire routine, without and with the troop helmet worn over top of the PPE.

[3] It is difficult to estimate the limit of detection of the method as it will vary by individual in part based on background particle generation, but generally speaking the method as performed will reliably measure fit factors of 40,000 or below. Differences above that value may not be significant between wearers and were not of interest in this study.
[4] Owing to limited time, the control individual was not tested.
[5] This has been observed to occur in a separate study measuring artifactual background contributions from individuals with beards, in a clean chamber.

Table V. QNFT fit factor results in various respirator configurations for eight wearers.

Headdress/beard	QNFT FF	C5	C5-NP	C5-PA	C4-NP	C4-PA
Medium beard Patka	Normal Breathing	43	61	59500	6	10300
	Head Turn	33	47	32300	8	13800
	Bend Over	32	44	46900	9	12400
	Total	**35**	**50**	**42800**	**8**	**12000**
Long beard Turban	Normal Breathing	14	16	171000	24	40200
	Head Turn	12	13	68500	50	45000
	Bend Over	12	26	121000	23	48400
	Total	**12**	**17**	**105000**	**29**	**44200**
Hijab	Normal Breathing	180	149	29500	102000	118000
	Head Turn	71	60	55800	1981	87900
	Bend Over	80	57	58300	463	127000
	Total	**93**	**73**	**43500**	**1122**	**108400**
Short beard Patka	Normal Breathing	20	18	150000	20	14600
	Head Turn	27	26	54600	24	18200
	Bend Over	20	17	115000	37	21700
	Total	**22**	**20**	**89200**	**25**	**17700**
Short Beard	Normal Breathing	327	132	143000		
	Head Turn	333	147	116000		
	Bend Over	45	111	164000		
	Total	**361**	**128**	**138000**		
None (control)	Normal Breathing	11700	33100	38100		
	Head Turn	11900	34200	62000		
	Bend Over	12900	28800	115000		
	Total	**12200**	**31900**	**58700**		
Short Beard	Normal Breathing	4	7	68600		
	Head Turn	6	10	110000		
	Bend Over	5	8	90800		
	Total	**5**	**8**	**86400**		
Long Beard	Normal Breathing	12	17	75700		
	Head Turn	10	18	157000		
	Bend Over	7	14	39900		
	Total	**9**	**16**	**67200**		

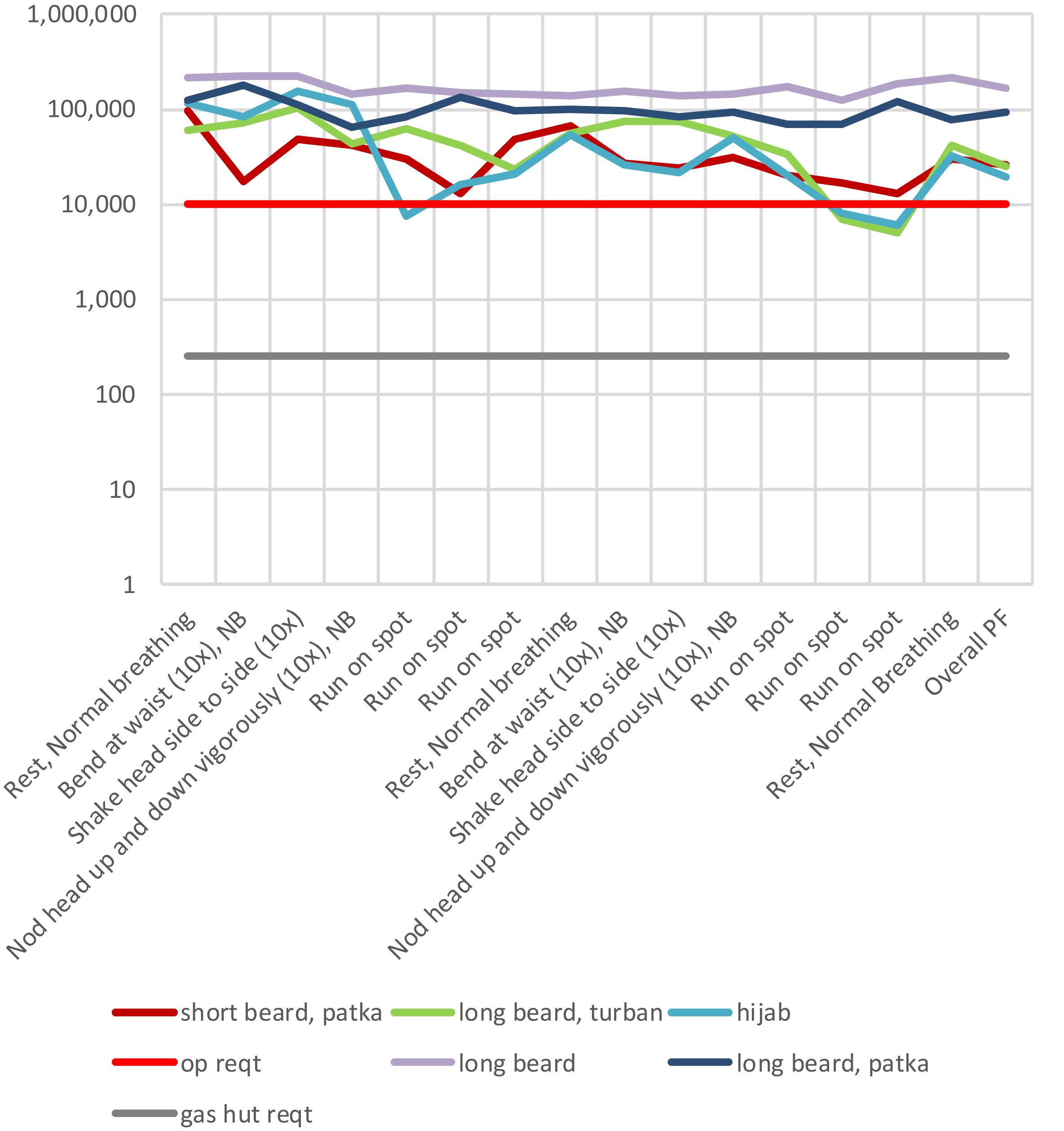

Figure 4. SWPF results for the C5-PA configuration as a function of individual activity and overall, for the gas hut activity routine performed by affected wearers.

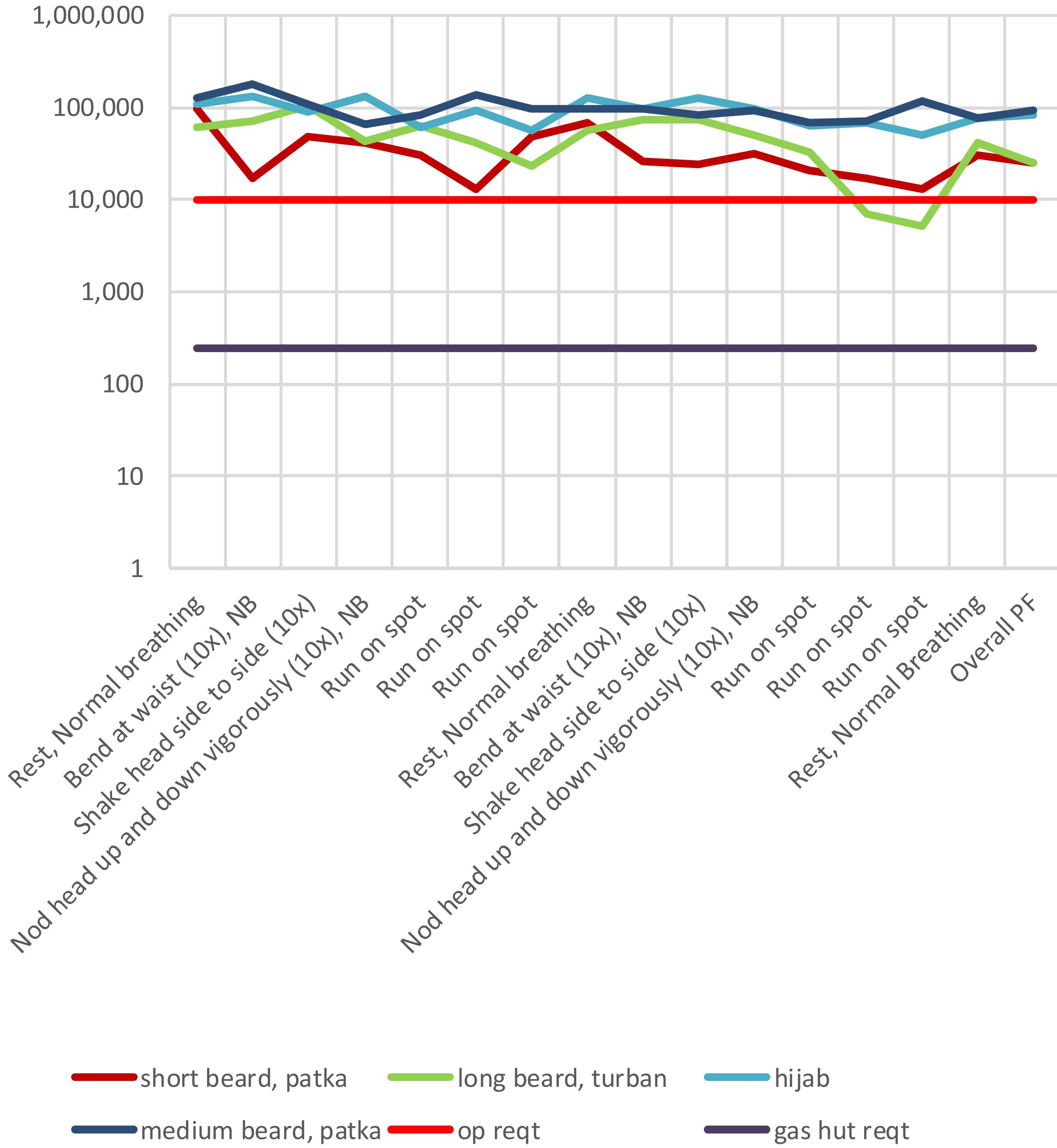

Figure 5. SWPF results for the C4-PA configurations as a function of individual activity and overall, for the gas hut activity routine performed by affected wearers.

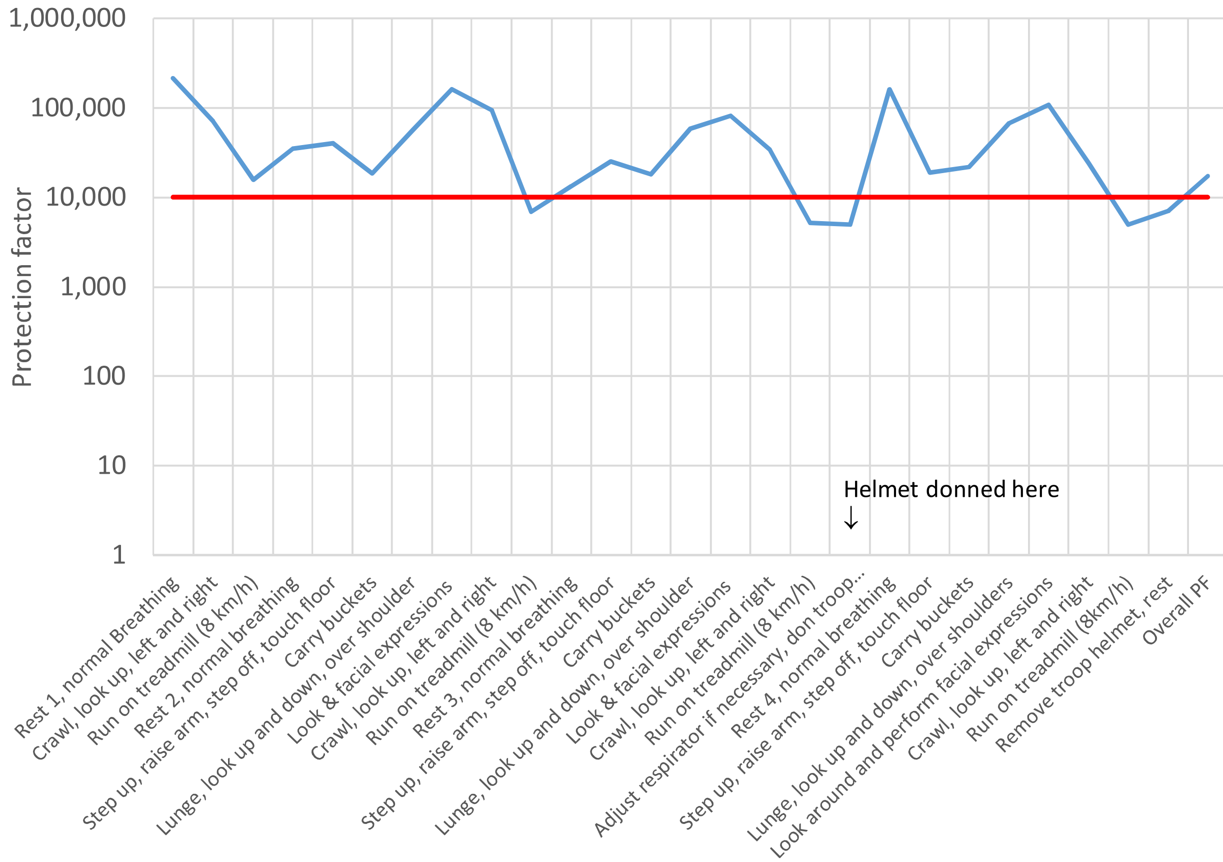

Figure 6. SWPF results as a function of individual activity and overall using the operational activity routine for one affected wearer in the C4-PA respirator.

QNFT and CS gas hut results

All bearded participants obtained a FF greater than 10,000 in the PA configurations and significantly below 10,000 in the NP configuration. None of the participants obtained the required fit factor of 250 in NP mode, while all exceeded both of the potential requirement values in PA mode.

All eight bearded participants successfully passed the gas hut for all entries when wearing the PA configurations for both the C4 and C5 respirators, with the exception of four participants who had training issues with the drills on their first entry but passed all subsequent entries. The procedure that required extra care required assuring that, during a canister change drill:

1) the blower motor had fully stopped after being powered off and prior to removing a canister, as otherwise the blower would draw unfiltered CS through the blower and into the breathing zone, and
2) when the blower motor was powered back on, the wearer kept their eyes closed and breath held for an additional 2 seconds, to clear out any unfiltered CS in the breathing tube and mask cavity before the next inhalation.

These results supported the prediction that individuals wearing the C4 or C5 in PA mode and who achieved a FF of at least 10,000 in that mode, can successfully pass through the gas hut with appropriate modifications to, and training in, the relevant drills. It is likely a much lower value would be adequate based on the worst-case theoretical HHR of 250. These early results suggest that such a PA configuration might also be adequate for other forms of training or operational use.

CONCLUSIONS

The result of the study is consistent with the prediction that individuals can successfully pass through the gas hut, if wearing either the C4 or C5 in PA mode and having achieved a FF of at least 10,000. It is appropriate for the CAF to continue to consider this approach as an interim solution to the issue of providing protection for the gas hut portion of recruit training to those recruits who cannot achieve adequate protection in the C4 or C5 CBRN respirator, until the later fielding of the unpowered solution under development specifically for training purposes. Additionally, for training and exercise purposes, the PA configuration could also be issued to CAF members with beards and/or headdresses that are required to perform annual refresher training, or participate in international field exercises in the absence of CBRN agents where CAF members are required to pass through the gas hut. The PA configuration has also shown promise for delivering operational levels of protection for military individuals with beards and/or headdresses, once fully proven by a combination of tests on a larger number of affected individuals and consideration of other operational requirements.

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