

Quantitative Fit Testing of Military Gas Masks with the TSI Portacount: Part I - Identifying the Limitations

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ABSTRACT

The Canadian Armed Forces is adopting quantitative fit testing (QNFT) to replace the qualitative fit test (QLFT) in the evaluation of the fit of the C4 gas mask on Canadian troops. The TSI Portacount Plus has been widely used in measuring fit factor (FF) during QNFT for commercial respirators and in self-contained breathing apparatus by the Fire Departments. This equipment is also OSHA-accepted. In adopting the TSI Portacount Model 8020 for our use, we experienced several difficulties. We found that naturally occurring ambient particle concentration at our location was insufficient for fit testing Canadian military C4 gas masks that required a fit factor of at least 6667. We found that certain exercises that are part of the OSHA 8-exercise fit test protocol are inappropriate and/or unnecessary for a particle counting instrument like the TSI Portacount, versus a forward light scattering photometer that employed corn oil aerosol. In this respect we have adopted a 3-exercise routine. This report details these problems and provides modified test conditions and procedure in conducting successful QNFT on military gas masks using the TSI Portacount.

Keywords: quantitative fit test, TSI Portacount, Dynatech system, Required Fit Factor, particle concentration, exercise routine, equipment limitations

INTRODUCTION

The Canadian C4 military gas mask was designed and developed in the 1980s. It was launched into service at the outbreak of the First Gulf War, and has proven to be extremely high performance equipment. When the C4 mask was developed, the quantitative fit testing (QNFT) with users was conducted with an early version of the Portacount and a Dynatech Frontier Respirator Fit Testing System Model 260BC using corn oil aerosol. The aerosol concentration was maintained at 10 to 35 $\mu\text{g/L}$ with a particle mass median diameter between 0.5 and 0.7 μm . The aerosol count was estimated to be about 2.4×10^5 particles/mL. Three forward light scattering photometers (FLSP) measured both the challenge and the inside-respirator concentrations to accuracies over a dynamic range of 10^6 . The operating principles of FLSP have been described in the open literature and will not be elaborated here. Required Fit Factor (ratio of aerosol concentration outside the mask to aerosol concentration inside the mask, as used by ANSI) for the gas mask was derived from the changes in the output voltage of a photomultiplier tube within each FLSP that occurred as the sample line aerosol was drawn through the measurement chamber. These voltage changes were amplified and recorded by a data acquisition system and processed by a microcomputer used to control the sampling and aerosol generation sequences. Since the C4 mask was designed for military purpose, it has to meet military standards. The military standard at that time (QSTAG 695) required that a negative pressure gas mask provided a maximum leakage rate of 0.015%. In terms of respirator fit testing this represents a required fit factor (RFF) value of 6667. It should

be noted that fit testing to a pass/fail level of 6667 is implemented for very specific military reasons, and may not apply to private sector fit testing where the pass/fail is typically between 100 and 1000.

QNFT with the Dynatech system was conducted as follows. A preliminary fit test on the subject with the gas mask was carried out. If an overall RFF lower than 6667 was obtained, then mask fitting was checked and adjusted (e.g., making sure that hair was not caught between face and the seal) before the subject proceeded to the exercise routine consisting of: normal breathing, deep breathing, head side to side, head up and down, reading aloud the "Rainbow Passage", counting aloud 1-30, facial expressions including grimace and yawn and finish with normal breathing again. At the time the C4 mask was developed, a commercial portable TSI Portacount using a different technology (condensation nuclei counting) was evaluated for its simplicity in conducting QNFT. The Portacount was small and light, and did not require a small room for containment or an aerosol generation devices like the Dynatech. The design of the Portacount allowed the use of particulates in ambient air as the challenge aerosol. This method of particle sensing counted particles down to $0.02\ \mu\text{m}$ in diameter over concentrations in the range of 0.1 particles/mL to 5×10^5 particles/mL. More specific information could be found in the operation manual of the Portacount.

At that time, we found that we could not compare data obtained between the Portacount 8010 and the Dynatech Frontier Respirator Fit Testing System, due to the difference in design of the two equipments. Thus, we concentrated our QNFT effort using the Dynatech system only. The size and the aerosol generation requirements for the Dynatech system limit its use to the laboratory only. Overall, using corn oil aerosol, we have shown that we could fit the 5th to the 95th percentile of the Canadian Forces population with a mask that have a RFF in excess of 6667.

In 2003, we investigated the replacement of the Canadian military combat spectacles with a commercial off-the-shelf device, and we employed the TSI Portacount Plus Model 8020 in measuring the required fit factor of the device inside the C4 gas mask. We had no experience with the Portacount Plus Model 8020 at the time, but we understood that it is widely used in measuring the fit factor for commercial and military respirators and for self-contained breathing apparatus by the Fire Departments. We followed the protocols as detailed in the instruction manual, and employed the same exercise routine listed. We obtained some unusually low fit factors for the C4 gas mask with or without the combat spectacles. Some of the measured fit factors fell below the pass/fail of 6667. This initiated the current respirator fit testing program at the Royal Military College. Specifically, we investigated three areas of respirator fit testing: (1) the replacement of QLFT with QNFT using TSI Portacount; (2) the determination of the operating envelop of the TSI Portacount and the equipment limitations; and (3) the development of a proper procedure to conduct QNFT given this equipment and its limitations. It is also important to develop a QNFT procedure that Canadian Armed Forces could conduct in the field. This report describes the preliminary results from our investigation, while a second report (Harrison & Liang 2005) will detail how quantitative solutions were developed.

MATERIALS AND METHODS

Test Subjects

A total of 25 Canadian troops (21 male and 4 female), ages 19 to 46 years, stationed at Canadian Forces Base in Borden, Ontario volunteered in this experiment. For the females, two of them wear small masks, one medium and one large mask. For the male volunteers, six wear small masks, ten medium and five large masks. This does not represent the typical distribution of nominal mask sizes in the Canadian Forces (Chamberland et al., 1998). Test subjects were asked to sit around for 5 minutes after donning the mask to bring down the threshold particle concentration inside the mask, before carrying out any exercises in the QNFT. The experimental protocols employed in this study were submitted to the Royal

Military College of Canada Research Ethics Review Board, and approval to proceed was obtained before the experiments took place, as human subjects were involved.

Quantitative Fit Test (QNFT) with TSI Portacount

The rationale for the set up and test conditions in conducting a QNFT in this laboratory will be elaborated in the next report (Harrison & Liang 2005). Instead of using ambient particles to conduct QNFT, we employed the TSI Model 8026 particle generator (using sodium chloride aerosols) to produce an ambient particle concentration between 40000 to 60000 particles/mL. To contain this aerosol concentration, we constructed a test chamber (4' x 8' and 8' high) as an enclosure for the aerosol. The chamber shown in Figure 1 is big enough to allow two people moving around freely and to conduct exercises without bumping into each other. It has double-door system to act as an airlock. It also has a glass window in front so that test operator could observe the test subjects while conducting the QNFT. In-mask aerosol concentration was sampled inside the nose cup using the TSI drink tube adapter.

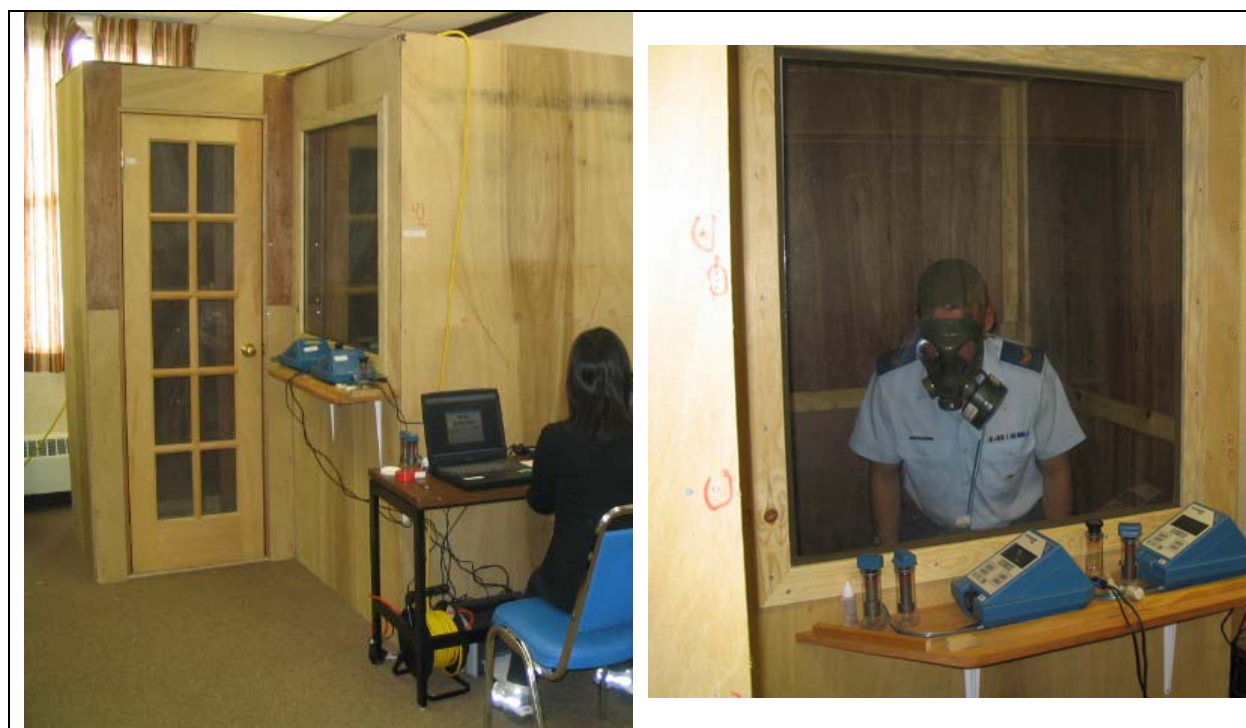


Figure 1. The test chamber.

RESULTS

Effects of Ambient Particle Concentrations

Back in 2003 when we used the TSI Portacount Plus Model 8020 for the first time, we experienced several difficulties when we attempted to measure RFF using ambient particles. The TSI Portacount Plus is operable with a minimum ambient particle concentration of 1000 particles/mL. There is usually very good ventilation in Canadian laboratories (air conditioning and winter heating) so that the ambient particle concentration is kept very low. With good ventilation, particle concentration may not be sustained even

with a burning candle. As the ambient particle counts drops, so does the measured fit factor. Thus, we have designed this experiment in which QNFT using the TSI Portacount was conducted on the same test subject, first inside a test chamber where aerosol concentration was maintained at 40000 particles/mL, and then without removing the mask, the test subject exited the chamber where fit factor was measured again, using room ambient particles. The test subject performed eight exercises as indicated in Tables I and II. Grimacing was conducted between talking and bend over for 15 seconds, but no fit factor was measured during this activity. As dictated by the OSHA fit test protocol, the test subjects waited 5 minutes between donning the mask and the beginning of the exercise routine.

The test chamber was set up with two Portacounts, while only one Portacount was available in the room set up for sampling with ambient particles. Thus, there were more data entries in Table I than in Table II. Numbers in italics and bold indicated that measured required fit factor (RFF) were below 6667 - the Canadian pass/fail criterion.

Table I. Measured Fit Factor Using Ambient Particles at 40000 Particles/mL

User	Normal Breathing	Deep Breathing	Side to Side	Up and Down	Talking	Bend Over	Normal Breathing	Overall
1	230000	277000	117000	111000	13900	295000	357000	67537
2	739000	163000	363000	227000	21300	231000	409000	102383
3	584000	117000	316000	397000	12900	23500	160000	49204
4	271000	47600	195000	191000	16100	90100	224000	62091
5	749000	269000	55000	385000	34400	497000	214000	170660
6	905000	136000	712000	283000	75200	199000	434000	205742
7	141000	79700	23300	42700	32900	6580	172000	25532
8	425000	166000	206000	148000	10500	152000	777000	56868
9	456000	689000	81200	112000	23600	88500	768000	87651
10	400000	160000	317000	205000	80500	222000	243000	185064
11	169000	579000	317000	122000	26600	129000	609000	106087
12	225000	307000	255000	368000	30600	206000	356000	128009
13	69100	146000	74100	114000	17200	127000	187000	60896
14	152000	198000	68400	18500	7240	35300	253000	27921
15	179000	183000	335000	257000	21800	174000	199000	93870
16	203000	191000	154000	222000	41400	174000	277000	128037
17	25000	135000	94700	213000	24500	225000	554000	94944
18	144000	140000	252000	3540	26500	742000	667000	20520
19	139000	104000	227000	44000	7780	96300	103000	36350
20	16300	66400	28100	88300	7840	116000	170000	26378
21	71600	399000	111000	156000	20400	90700	81400	67164
22	76600	47100	44000	29400	9800	83100	63800	31706
23	294000	323000	210000	411000	44600	182000	785000	163238
24	656000	65900	176000	234000	21700	114000	288000	82371
25	92900	102000	33300	138000	14300	67900	174000	47218

There are two failures observed in Table I. One occurred when the test subject was performing the bend over activity, while the other one occurred during the head up and down activity. The operator of the Portacount thought that the sampling tube kinked during these two measurements, leading to the low fit factor obtained. Furthermore, the catastrophic failure observed in Table II for Subject #14 was attributed to the test subject's coughing during the measurement. The increase of failures shown in Table II for the measured fit factor causes errors on the "safe side" if we consider fit factors as concentration ratios only. However, current doctrine dictates that if a gas mask user failed the QNFT, a different mask will be issued until he/she passes the QNFT. If a problem resides with the instrument or the procedure employed, and not with the user, it is important to differentiate this difference, as replacing gas masks will increase logistic burden, among many other problems. Besides the fact that there were more failures in Table II, the magnitude of the measured RFF for each subject during each of the 8 exercises was much higher in Table I than in Table II. It is understood that fit test using TSI Portacount is really a pass/fail test, and not absolute particle counts as obtained with the Dynatech system. However, the test subjects did not remove the mask between these two tests (at 40000 particles/mL and ambient particles), the fundamental fit of the mask could not have shifted and caused any transient leaks (Crutchfield et al., 1999). We attribute the lower numbers observed in Table II to the lower ambient particle concentration used. This is because that exhaled particles become more significant compared to particles that leak into the mask. In the next report (Harrison & Liang 2005) we will go into more detail on this issue.

Table II. Measured Fit Factor Using Room Ambient Particles (ca. 2000 particles/mL)

Subject	Normal Breathing	Deep Breathing	Side to Side	Up and Down	Talking	Bend Over	Normal Breathing	Overall
1	22000	25300	18600	13800	2490	19200	49800	10219
2	28700	20000	39400	13200	1560	16700	33400	7635
3	5370	5550	5830	6140	473	2150	2460	1899
4	64500	48200	17900	19600	2430	31100	120000	11762
5	118000	70000	170000	54200	2060	13400	62900	11235
6								
7								
8								
9	23300	30100	14800	18200	2080	5050	7490	6924
10								
11	26100	48700	36000	16700	2200	9980	61100	9754
12								
13								
14	18000	10000	5790	7	672	5210	21100	48
15	11600	13200	22900	22500	1010	10400	50500	5162
16								
17								
18	22700	18900	12000	6160	1820	22400	12000	6862
19	20500	28000	52400	45700	1000	26700	15600	5705
20	237000	28200	23700	20800	1770	17800	212000	9261
21	23400	14800	11500	22100	1180	8140	33300	5632
22	17300	12000	9910	11100	1270	14200	15900	5587
23								
24	4070	46300	104000	102000	2700	79000	17500	9630
25	37600	99900	17700	6130	641	4910	40300	3423

Dr. Zhuang and his colleagues (Zhuang et al., 2004) had not found any significant differences among ambient aerosol concentration levels to the resulting fit tests. Furthermore, they also found that "talking", "bending over" and "moving head up/down" are critical in determining the overall fit factor. In this study we have found that almost every exercise in the OSHA routine affected the fit factor when ambient particles were used. In the next report (Harrison & Liang, 2005), we will be presenting more data supporting this.

Measured Fit Factor vs Ambient Particle Concentrations

With two sodium chloride generators, we were able to produce aerosol concentrations in excess of 60000 particles/mL inside the test chamber. Figure 2 illustrates the dependence of measured required fit factor on ambient particles concentrations for a typical test subject.

All test subjects were first connected to a Portacount until the sampling tube registered no particles (which may last to more than 15 minutes), then moved between four chambers where different ambient particle concentrations (ca. 5000, 20000, 35000 and 60000 particles/mL) were set up, and fit factor measured for a 3-exercise (normal breathing for 1 minute, repeat bending over for 1 minute, and then shake head rigorously for 3-5 seconds, followed by normal breathing for the rest of the minute) routine. The gas mask was not removed the whole time during the experiment. In actual fact, with three TSI 8026 particle generators, we were able to generate particle count in excess of 150000 particles/mL, and fit factors in the range of 300000 was obtained. A second report (Harrison & Liang 2005) will detail how we determined that the optimum ambient particles concentration lies between 40000 to 60000 particles/mL.

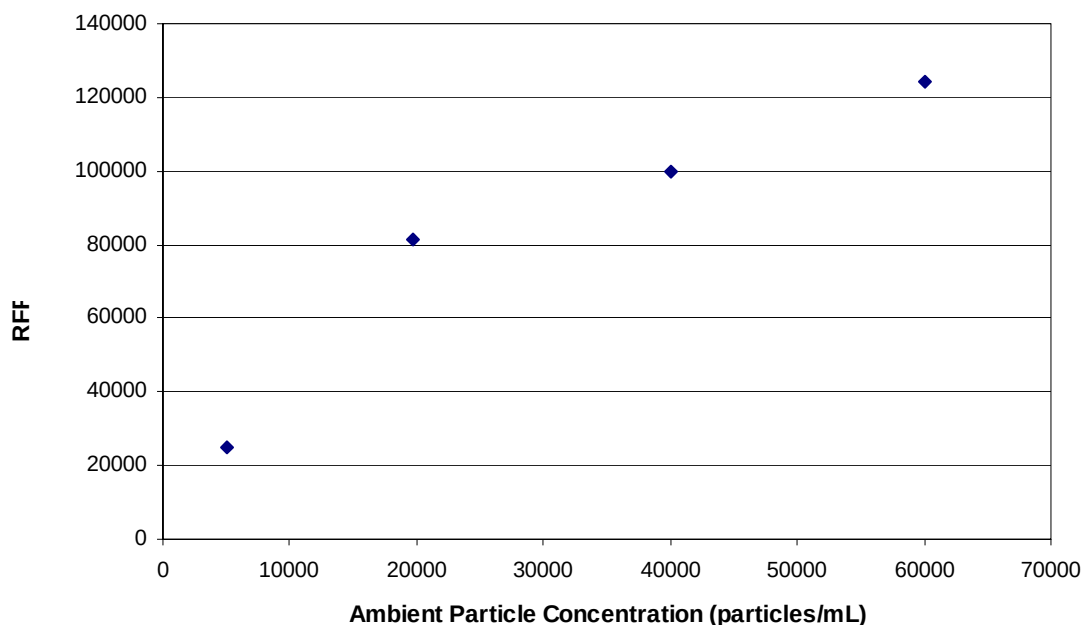


Figure 2. Measured required fit factor vs ambient particle concentrations.

Exercises Performed During QNFT with TSI Portacount

The current OSHA procedure in conducting QNFT requires gas-mask users to perform 8 exercises, listed in the Introduction section, similar to Tables I and II with an additional "grimacing" after the talking exercise. We have looked at an abbreviated 6-exercise (talking and grimace removed) and then a 3-exercise routine - one minute each (normal breathing, repeat bending over and shake head rigorously for 3-5 seconds). The intention to shorten the exercise routine was considered here not to reduce the time required for the QNFT, but in an effort to optimize the procedure.

As could be observed from Tables I and II, the "talking exercise" is highly dependent on the aerosol concentration. Practically, nobody failed "Talking" in Table I compared to Table II. Talking was not a problem for the Dynatech system using corn oil aerosol, as the FLSP was able to differentiate between oil aerosol and lung-exhaled particles. It will be shown in our next report (Harrison & Liang 2005) that lung-exhaled particles are produced when test subjects talk, thus interfering with the QNFT results.

Removing talking and grimace reduces the procedure to a 6-exercise routine. We conducted a series of experiments with 10 test subjects comparing the measured fit factor using this 6-exercise routine to a 3-exercise routine put forth by Crutchfield (Crutchfield et al. 1999), i.e., normal breathing (NB), repeat bending over (BO) and shake head (SH) for 3-5 seconds. We considered that the head side to side and up and down activities might be combined into a single head shaking motion. Thus, there is always room to improve the exercise routine required for the QNFT. Results comparing the two exercise routines are shown in Table III for two typical subjects. Taking into account the standard deviation associated with fit factor measurements obtained by TSI Portacount, we did not find too much difference in the measured RFF for both exercise routines. The important point to note is that if a wrong-sized mask was issued, the measured fit factor was able to identify the situation.

Table III. Fit Factors for 6-Exercises vs 3-Exercises

Subject 1				Subject 2			
correct-size mask		wrong-size mask		correct-size mask		wrong-size mask	
6exercise	FF	6exercise	FF	6exercise	FF	6exercise	FF
NB	389000	NB	5110	NB	51100	NB	133
DB	22600	DB	7750	DB	60100	DB	8380
SS	687000	SS	20300	SS	51700	SS	2160
UD	225000	UD	111000	UD	11300	UD	15400
BO	284000	BO	4900	BO	132000	BO	638
NB	724000	NB	176000	NB	159000	NB	27700
overall	104129	overall	9399	overall	76662	overall	702
3exercise	FF	3exercise	FF	3exercise	FF	3exercise	FF
NB	221000	NB	22100	NB	98400	NB	243000
BO	28800	BO	14600	BO	122000	BO	699
SH	77000	SH	6600	SH	12300	SH	14700
overall	57434	overall	11310	overall	30102	overall	1996

CONCLUSIONS

In this report, we have identified three major concerns when using the TSI Portacount Model 8020 for fit testing military gas masks that require a fit factor of at least 6667:

1. Naturally occurring ambient particle concentration in our laboratory may not be high enough to measure high fit factors accurately;
2. Fit factors measured during the "talking" exercise seem artificially low compared to other exercises; and
3. It may not be necessary to perform more than 3 exercises during a fit test.

We plan to quantify these problems and recommend some experimental procedures to overcome them.

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