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**A Study of the Differences in Respirator
Fit Factor Values Between Years and Masks**

A Plan B paper presented to the
School of Public Health
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In partial fulfillment of the requirements for the degree
Master of Science

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MASTER

The research was performed under appointment to the
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Chapter 1 Introduction

1.1 The Respiratory Protection Program at a National Laboratory

The work described in this report was carried out at a national laboratory of the Department of Energy, during the time that the author was engaged in a Department of Energy Industrial Hygiene Graduate Fellowship.

The national laboratory had a respiratory protection program with approximately 50 employees participating. The program was in place to protect employees from over-exposure to airborne contaminants while engineering and work practice controls were being installed and implemented. It was also in place to protect workers in situations where engineering and work control practices were not feasible, such as during maintenance and repair work, as well as in situations where engineering and work practice controls were not enough to lower the exposure to or below the Permissible Exposure Limit (PEL) as set by the Occupational Safety and Health Association (OSHA) as an eight-hour time weighted average (TWA) or an excursion limit. Respirators were also used for emergencies by the emergency response team.

Twenty five percent of those employees participating in the respiratory protection program worked in Facilities Management and used their respirators primarily to reduce exposure to asbestos when doing building maintenance and occasionally to reduce nuisance dust exposure during grinding and sanding operations. Almost all of the other participants in the program were researchers with varied projects being conducted in their labs. High Efficiency Particulate Air (HEPA) filters, organic vapor cartridges and combination filter/cartridges were used by these employees. The fit test procedure for respirators being used for protection against asbestos is the most stringent and was used for all fit tests at the lab.

1.2 The Field of Industrial Hygiene

The field of industrial hygiene is dedicated to the anticipation, recognition, evaluation and control of occupational health hazards that may cause sickness, impaired health or significant discomfort among workers or citizens of the community. Through training and education an industrial hygienist can anticipate and recognize these hazards. Through quantitative data gathered to determine the level of contamination during certain operations, an evaluation can be made and an opinion given as to the degree of risk associated with exposure to certain hazards. Controlling the occupational health hazards is of great importance and is accomplished by either reducing or eliminating the exposure.

The basic means for controlling exposure is through the engineering control methods of substitution (which involves changing the processes or materials to ones less hazardous), isolation, and local and general exhaust ventilation. In addition, there are administrative controls for reducing exposure, e.g., rotation of workers and the proper use of appropriate personal protective equipment. The need for certain control measures depends upon the hazard to be controlled, the level of contamination, the exposure level and the established limit values for that hazard. Personal protective equipment is meant to be used as a last resort when engineering and administrative controls do not lower the exposures to permissible levels. An example of personal protective equipment to reduce exposure to airborne hazards such as aerosols would be the types of respirators which are the focus of this paper.

1.3 History of Respirator Use

There are many different kinds and styles of respirators available today, which was not so even fifty years ago. Many developments have occurred in recent times although there has probably been some form of respirator in use for the last 2000 years. According to Brown (1937), the first mention of respirator use was in the time of Pliny the Elder (23-79 AD). Loose bladder skins were said to have been pulled over the face to protect against inhalation of vermilion dust. Because working in dusty environments is so irritating it is possible that, in times even earlier than this, people used some sort of filtering device over

their noses and mouths to protect against inhalation of the dust. Miners during the 16th century were reported by Agricola to have used fibrous material around the face to protect against dust inhalation (Brown, 1937). According to Hounam *et al.* (1964), high efficiency filtering respirators for substances more toxic than silica were not widely used in industry before at least 1964. Prior to that, they were largely developed for servicemen and civilians in wartime.

The concept of supplied air also began in ancient times and was used to protect divers. Originally, divers probably used a hose-type device and inhaled air by the use of their lungs alone (not supplied air); but this eventually led the way to positive pressure supplied air, in the form of bellows which were used to force air through the hoses in the 17th century. Because of the need for fresh air in rescue and fire fighting in mines, a supplied atmosphere apparatus was developed for that purpose in 1853 (Brown, 1937). This is similar to the present-day devices that provide a supplied clean atmosphere.

Protection against the inhalation of gases and vapors was recognized as a high priority need during World War I. After the war, accidents and deaths associated with the use of army gas masks for purposes in industry settings for which they had not been designed (and provided no protection) led to the development of more appropriate respirators for gases and vapors.

The physical principles of mechanical filtering of fibrous materials and of properly fitting half face mask respirators were not studied extensively until World War I. Then, up to and during World War II, there was considerable research and development activity. The recent past has seen the advent of a great number of different kinds of respirators with increased protection capabilities. This list of respirators includes particulate filter, chemical cartridge and gas masks, air line, powered air-purifying, self-contained breathing apparatus and supplied air suits. Respirators chosen for any respiratory protection program in the United States should be among those approved by the Mine Safety and

Health Administration (MSHA) and the National Institute for Occupational Safety and Health (NIOSH) under the provisions of 30 CFR Part 11.

1.4 Respiratory Protection Regulations

The federal regulations clearly state that the primary objective in the control of those occupational diseases caused by breathing airborne contaminants is to prevent the air from becoming contaminated in the first place (20 CFR 1910.134). This can be accomplished with engineering controls such as isolation, substitution and ventilation. This regulation makes it clear that respirators shall be used only if engineering controls are not feasible or practicable, while the controls are being put into place, or during emergencies. There are several requirements to be met in a respiratory protection program. The requirements include the following. A written standard operating procedure for the selection and use of respirators is required. The respirator should be selected based on the hazard. The users must be instructed and trained on the proper use and limitations of respirators. Regular cleaning, disinfecting and inspection of the respirator is required. Respirators are to be stored in convenient, clean, and sanitary locations. Surveillance of work area conditions and degree of employee exposure must be maintained. The respiratory program must be continually evaluated and inspected to determine its effectiveness. Persons will be assigned to respirators only after they have been determined to be physically able to perform the work and use the equipment. Selecting respirators from among those jointly approved by MSHA and NIOSH under the provisions of 30 CFR part 11 is required. The regulation goes into detail regarding these different aspects of a respirator program (see Appendix A). Proper selection of respirators shall also be made in accordance with the American National Standard Practice for Respiratory Protection Z88.2-1992.

Chapter 2 Aims of the Study

This project was concerned with an evaluation of certain aspects of performance of respirators recommended at the DOE facility in question for worker protection against exposure to airborne contaminants.

2.1 Primary Aims

One primary aim of this study was to compare the fit factor values, obtained in the summer of 1994, of the rubber half face respirators normally worn by the employees, (which were either 3M, Willson or MSA masks) with those of the previous year. The aim was to determine how well the values for 1993 would enable the prediction of values for 1994 and the validity of the fit testing procedure over a period of time where human factors can change.

The other primary aim was to compare the 1994 fit factor of the employee's regular rubber half face mask to that for a reusable, disposable HEPA filter mask, the 3M 9970. The laboratory wished to make a determination about whether they would offer the 9970 mask to those employees whom it fit satisfactorily, and whose needs it met in the respiratory protection program. The purpose was to determine if (a) the 9970 respirator and the rubber half face masks could achieve comparable fit factors, and (b) if the 9970 should be offered to those employees who needed protection from dust, mist, fume and radionuclides.

2.2 Secondary Aim

The secondary aim of the study was to analyze the different indices of performance of the 9970 disposable respirator as determined by the individual wearer. These indices were comfort, protection, wear time, ease of putting on, ease of removal, fit to face and durability. The wearer was asked to rate these indices based on their perceptions after wearing the respirator for a short time. It was believed that, if the employees perceived the 9970 mask to be comfortable and easy to wear, they would wear it more frequently

and for longer duration, thereby increasing their level of protection to airborne contaminants even if the fit factor values obtained through the fit tests for the 9970 were not as high as those obtained for their regular rubber half face masks.

Chapter 3 Aerosol Science Background

3.1 Airborne Hazards

An aerosol consists of either solid or liquid particles suspended in a gas. The usual suspending gas is air. The particles range greatly in size, from 0.001 to over 100 μm .

There are various systems which are considered aerosols. These are:

Dust - a solid-particle aerosol of submicrometer to size visible with the naked eye, resulting from mechanical disintegration of solid material

Fume - a solid-particle aerosol generally less than one micrometer, produced by the condensation of vapors or gaseous combustion products

Smoke - a liquid- or solid- particle aerosol usually less than one micrometer, resulting from incomplete combustion

Mist - a liquid-particle aerosol from submicrometer to about 20-micrometer size, formed by condensation or atomization

Spray - a liquid-particle aerosol from one to about 20-micrometer size, formed mechanically from bulk liquid

These are some aerosols in some situations that may require respiratory protection. Aside from aerosols, gases, vapors and radionuclides are other hazards that may require respiratory protection to be worn. For aerosols, because inhalation is the main route of exposure, it is important to consider not only different kinds of aerosols but also their particle size distribution, morphology, and concentration.

There are three health-related aerosol size fractions which are now widely considered to provide the best basis of criteria for industrial hygiene sampling (Vincent, 1995). The first is the inhalable fraction (see Figure 1) which is that fraction of particles which enters the respiratory system through the nose or mouth during breathing. The particles range in aerodynamic diameter from submicrometer to at least 100 μm . The second fraction (see Figure 2) is termed thoracic, and comprises particles from submicrometer to approximately 30 μm in aerodynamic diameter, and enter into the respiratory tract as far as the lungs below the larynx. The third fraction (see Figure 3) is termed respirable and consists of inhalable particles which reach the alveolar region of the deep lung. They lie in

the range from submicrometer to 10 micrometers in aerodynamic diameter. It is important to determine the different particle size fractions and the particle size distribution for an airborne hazard because different aerosols cause different diseases depending on where they are deposited in the respiratory tract.

Particle morphology may also be important when considering aerosol hazards. Particles of certain shapes may have an easier or harder time entering and/or remaining in the respiratory tract. Long, thin asbestos fibers, for example, may penetrate deep into the lung and once deposited there may, by virtue of their physical size and shape, be very difficult to clear and so be retained indefinitely.

Concentration of the aerosol is important because it relates to the level of exposure. For most aerosols this is expressed in terms of the mass concentration (e.g., mg/m^3). The Threshold Limit Values (TLV) are recommended by the American Conference of Governmental Industrial Hygienists (ACGIH) and are the concentrations of relevant aerosol fractions of specific substances that should not be exceeded over a time-weighted eight hour day. Permissible Exposure Limits (PEL) are regulatory standards that must be adhered to in order to meet OSHA requirements. They are also eight hour time-weighted averages.

3.2 Summary of Filtration Theory

A filter is made up of many fibrous elements. Filter efficiency can be studied at the basic level by considering only a single fiber. We consider this in order to understand the different physical mechanisms by which a particle may be collected. When considering collection efficiency, it is assumed that if a particle comes into contact with the fiber it is removed from the air stream permanently. Aerosol filtration occurs by five depositional mechanisms that take place in the filter. These five mechanisms are interception, inertial impaction, diffusion, gravitational settling and electrostatic attraction (Hinds, 1982).

Interception occurs when a particle follows a gas streamline and comes within one particle radius of the surface of the fiber. When the particle touches the fiber, the particle is deposited because of its finite size. Interception is governed by the ratio of particle diameter to fiber diameter.

Streamlines of the airflow move around fibers and particles, due to their inertia, may cross the streamlines and so impact into the fiber. This mode of deposition is known as inertial impaction. Impaction depends on the diameter and velocity of particles and on their density and shape. The effects of this mechanism increase with increasing face velocity, particle diameter and particle density and with decreasing fiber diameter.

Particles may also deposit on a fiber of the filter by diffusion. The irregular small movements of a particle caused by gas molecules hitting the particle are referred to as "Brownian motion", and the effect is greater for smaller particles.

Gravitational settling is associated with the force of gravity on the particle, causing it to be pulled down out of the air stream and onto the fiber of the filter. This mechanism is usually negligible in respiratory filtration in relation to the other mechanisms described.

The fifth deposition mechanism is electrostatic deposition. The presence of charge on the particles or the fibers of the filter will tend to increase the collection efficiency because charged particles will be attracted to opposite charged fibers by Coulombic attraction.

As filters become loaded, the efficiency increases due to the greater likelihood of impaction, interception and diffusion that can take place not only on the fibers but on the collected particles as well. However, for filters like those used for personal respiratory protection, the effect of filter clogging is usually small.

For a particle size of approximately 1 μm , neither interception, impaction, gravitational settling nor diffusion are very effective and a minimum in overall collection efficiency

occurs. There is also, for each particle size, a face velocity at which minimum collection efficiency will occur. These two factors can reduce the collection efficiency of a filter.

Another factor that affects the filters is pressure drop. This is the filter's resistance to air flowing through it. The pressure drop is proportional to filter thickness, at a given face velocity. As filters become loaded, the pressure drop increases. When it becomes difficult for a person to breathe through a respiratory filter element, the filter element should be changed (Hinds, 1982).

3.3 Leaks

Filter penetration and facial seal leakage are the two primary routes of inhalation exposure for a respirator wearer. The mass concentration inside and outside of the respirator and the ratio of the two is important when trying to determine the fit factor (see below). The HEPA filters, which are 99.97% efficient for a particle size of 0.3 μm , allow filter penetration to be neglected when evaluating aerosol leakage into the face mask of a respirator (Holton *et al.*, 1987).

Facial seal leakage is the most important route of leakage into negative pressure respirators equipped with HEPA filters. According to Manninen *et al.* (1988), ten different factors affect the facial seal leakage of half face mask respirators. They are:

- the size and shape of the user's face, particularly the nose and chin;
- the size, shape and adaptation of the facepiece of the mask (the most critical distance being from the bridge of the nose to the point of the chin);
- missing teeth;
- loss of weight after initial adequate fitting;
- lined, wrinkled faces;
- shaving habits (beards, whiskers, sideburns can all affect fit);
- use of spectacles;

- care in placing mask on face and amount of experience using personal protective devices;
- humidity and temperature of the air;
- airflow rate, exertion and activity of the worker (Manninen *et al.*, 1998).

By controlling for these different factors, the face seal leakage (hence, inhalation exposure) can be reduced.

3.4 Fit Factor

In order for a respirator to optimally protect a wearer from aerosol exposure, the respirator must fit to the face so as to achieve minimal facial leakage. If there are leaks, contaminated air may flow through them and so expose the wearer. A proper fit can be obtained by choosing a respirator of a shape and size that best fits the wearer's face. To determine the effectiveness of the seal, a fit test is performed (Xu *et al.*, 1991).

The two types of fit tests available are either qualitative or quantitative in nature. Both are conducted in the laboratory before the worker goes to the actual worksite. Both tests take approximately 15 minutes. Qualitative tests rely on the wearer's sense of taste or smell or cough reflex to detect penetration of an appropriate test agent while the respirator is worn in a closed test chamber or while wearing a hood. The test is passed if the wearer cannot detect the test agent while wearing the mask and the test is failed if the wearer can detect the test agent while wearing the mask.

Quantitative fit tests rely on instruments instead of human sensation and these instruments provide a numerical value, a fit factor, which offers a significant advantage (Myojo *et al.*, 1994). The fit is expressed quantitatively by comparing the concentration of contaminant outside (C_o) with that inside (C_i) the respirator (Xu *et al.*, 1991). The fit factor, FF, is expressed as:

$$FF = C_o/C_i \quad (3.1)$$

When calculating the quantitative FF for a half face mask, a score of 100 must be achieved in order to have an acceptable fit. The higher the fit factor the better the fit. (This accounts for a safety factor of 10 times the assigned protection factor of a half face mask respirator.)

For the quantitative fit test, the aerosol from inside the mask is collected through a sample probe permanently attached to the mask or from a removable sampling adapter which can be put directly on the wearer's own respirator. Both methods are acceptable, although the latter is more so because it allows the actual respirator worn in the workplace to be evaluated. According to Johnson *et al.* (1992), measuring the fit factor quantitatively first with the removable sampling adapter and the wearer's own mask and then with a mask that has a permanent sampling probe results in two fit factors that are within 10% of each other (Johnson *et al.*, 1992).

While both methods provide similar results, Xu *et al.* (1991) claimed that the position of the sampling probe and the site of the leak strongly affect the measured aerosol concentration inside the mask because the probe enables sampling from only a fraction of the volume inside the mask. The sample may or may not be representative. Air might not be thoroughly mixed within the mask during the wearer's breathing cycle (Xu *et al.*, 1991). Hewett *et al.* (1993) also claimed that in-facepiece sampling without regard for the breathing cycle results in an underestimation of the actual in-facepiece concentration. Therefore, overestimation of the fit factor occurs. The reasons for this underestimation of in-facepiece concentration include: lung deposition; inertial deposition at the inlet of the sampling probe; line losses from probe inlet to sampling machine; and, non-representative sampling within the facepiece (Hewett *et al.*, 1993).

There are many related terms regarding respirators and their fit. Fit factors were measured in this study. The fit factor is a measure of how well a respirator fits and is the ratio of outside mask to inside mask concentration. It is not measured in a workplace setting. Protection factor (PF) is used to describe the actual protection to the wearer by

the respirator and is also the ratio of outside mask to inside mask concentration. Actual protection factors provided by the respirator in the field may differ substantially from lab-determined fit factors. There are different kinds of protection factors. Individual or classes of respirators have an assigned protection factor (APF) which is the minimum level of workplace respiratory protection that would be provided by a respirator or by a class of respirators if they were functioning properly and the users were properly fitted and trained. The APF would be used when deciding which respirator to use in a specific work situation depending upon the hazard. The maximum use concentration (MUC) of a respirator can be determined by multiplying the APF and the Permissible Exposure Limit (PEL). The workplace protection factor (WPF) is a measure of the actual protection provided by the respirator in the workplace. The ratio of outside mask to inside mask concentration must be determined while the respirator is properly worn and used in normal work activities. The effective protection factor (EPF) estimates the effectiveness of respirator use policies rather than performance capability; it includes in-facepiece sampling during periods of respirator use as well as non-wear time. Other protection factors include program protection factors (PPF) and simulated workplace protection factors (SPF) (Colton, 1992).

Chapter 4 Methods and Materials

4.1 Experimental Strategy

As stated earlier, it was one aim of the study to examine the relationship between past fit factor (FF) values and current fit factor values for the same mask. The strategy to achieve this was to perform fit tests on a range of respirator wearers to obtain their current FF values and to gather their past FF values from records.

A second aim of the study was to examine the relationship between current FF values of the respirator wearer's normally-worn rubber half face masks and the 9970 disposable half face masks. The strategy to achieve current fit factors was to fit test for both types of masks during the same 1-hour period.

A third aim of the study was to evaluate employee perceptions of the 9970 mask. The strategy to achieve this was to allow the mask to be worn for several minutes before administering a questionnaire. The questionnaire used a 5-point Likert scale as an acceptability index, ranging from 1 (much less acceptable) to 5 (much more acceptable). The participant was asked to rate his/her perception of the 9970 mask versus a normally-worn mask. The questionnaire was administered by the author to assure understanding of the questions by the respondents.

4.2 Study Protocol

The DOE national laboratory where the study was conducted had approximately fifty participants in its respiratory protection program. As many as possible were recruited for participation in this study. Their annual or semi-annual fit tests were conducted during the summer of 1994. It was possible to schedule such a large number of fit tests during the three-month period because there were many workers overdue for testing. The fit tests performed using the 9970 masks were conducted at the same time as the fit test for their regularly-used rubber half face masks.

Before beginning the fit tests, the subjects completed a medical questionnaire form which, if everything was answered in the desired way, allowed the fit test to proceed. If any subject had not had a physical within the last year, or had certain respiratory problems, they were referred to the Department of Occupational Medicine and the fit test procedure was not performed.

Each subject's rubber half face mask was then inspected for worn parts, cartridges or filters, and the general physical condition of the mask (including the straps). The subjects were instructed to check their mask each time they cleaned and disinfected (when it appeared soiled) and, especially if they did not perform the maintenance, before donning. After reviewing the donning and doffing procedures, the subjects were asked to put on the mask. Negative and positive pressure tests were performed to check the seal and fit, and the wearers were reminded to perform those checks before each wearing. The quantitative fit test for their regular mask was then performed using the Portacount (TSI, Inc., St. Paul, Minn.), an aerosol particle counter which is discussed below. Either a sampling probe was attached to their own masks or the subjects wore a mask of the same manufacturer's model with the permanently attached sampling probe. The quantitative fit test (QNFT) protocol (see below) was followed and the resultant fit factor was noted.

If the subject had agreed to take part in the second part of the study, they were asked to choose either a medium or large 9970 mask and try it on. They were instructed on the correct donning and fitting procedures. In order to acclimatize themselves with the respirator and wear it for a few minutes, they were given respirator safety information sheets to read before the questionnaire was administered and the QNFT performed. The questionnaire (see Appendix B) contained questions regarding perception of comfort, protection afforded, length of time of wear, ease of putting on, ease of removal, fit to face and durability of the 9970 mask versus the normally-worn mask. The 9970 masks were special fit testing masks that had the permanent sampling probe affixed in the center of the mask above the exhalation valve, and so were not intended for actual use. The QNFT protocol was followed and the resultant FF value was noted.

4.3 Quantitative Fit Test Protocol

The QNFT was performed according to the requirements of the Asbestos Standard (29 CFR 1910.1001), chosen because these are the most rigorous available. While the worker was wearing the respirator, tubing was connected from the sampling probe or sampling adapter to the Portacount instrument. The testing procedure involved having the worker perform exercises while wearing the mask to simulate movements made in the work setting. The Portacount was set for nine specific exercises (as the asbestos regulations require) and would signal when it had collected enough samples and it was time to move on to the next exercise (usually after one minute). The exercise regime was as follows: normal breathing; deep breathing; turning head side to side; nodding head up and down; reading aloud (a poem, "The Rainbow Passage," was read because it incorporated various sounds of the English language); grimacing; bending over and touching toes; jogging in place; and, finally, normal breathing.

4.4 Portacount Machine

The QNFTs were conducted using the Portacount, Model 8010 (TSI, Inc., St. Paul, Minn.). It is a continuous-flow condensation nuclei counter (CNC) which works by sequentially sampling the ambient and in-the-mask fine particle concentrations and calculating a FF for each test cycle and an overall FF according to the following equation:

$$\text{overall FF} = \frac{N}{1/\text{FF}_1 + 1/\text{FF}_2 + 1/\text{FF}_N} \quad (4.1)$$

where: FF_x = fit factor for each test cycle

N = number of test cycles (9 in this case)

The Portacount is sensitive to particles with diameters as small as 0.002 μm . The ambient air and in-the-mask particle concentrations were recorded via a strip chart recorder, along with fit factors for each test cycle and the overall fit factor. An advantage of using the Portacount is its ability to use pre-existing ambient aerosols as the test aerosol instead of having to use a booth and a test aerosol.

4.5 Respirators Used in the Study

4.5.1 Rubber Half Face Respirators

There were three brands (in two or three sizes each) of respirators that the employees had available to them and were being used at the time of the study. They had been previously fit and fit tested with the respirator that best matched their facial structure and exposure needs. These respirators were rubber half face masks with twin filters made by 3M (Easi-Air), Willson (AR700), and MSA (Comfo). They were recommended for use with either dust, mist, fume and radionuclide filter elements, or gas and organic vapor cartridges. These respirators were not intended for use in environments immediately dangerous to life or health (IDLH) or in atmospheres containing less than 19.5% oxygen. These respirators had an APF of 10, which means they could provide protection of up to ten times the PEL or TLV or other exposure limits provided they were fit and worn correctly. These masks were all available with an attached sampling probe in order to perform fit tests. An in-facepiece sampling adapter device was also available to perform fit tests while the employees wore their own respirator.

4.5.2 Disposable, Half Face Mask, High Efficiency Respirator (3M 9970)

This study was conducted, in part, to determine if the 3M Model 9970 should be added to the list of respirators available for use at the national laboratory. Until such a decision was made, the mask was only available for fit testing purposes and not for use in the lab. For the study, the respirator was available in sizes 'medium' and 'large'. This respirator was recommended for use for protection against dusts, mists, fumes and radionuclides and could not be used for gases, vapors, paint sprays, asbestos or sandblasting. This respirator was not for use in IDLH environments nor atmospheres containing less than 19.5% oxygen. This respirator was lighter than the rubber half face respirators and had an APF value of 10 which means that it could provide protection of up to ten times the PEL or TLV or other set concentration exposure limits for the contaminants it protects against provided it fits and is worn correctly. This respirator had a permanent probe installed for quantitative fit testing.

Chapter 5 Raw Data

Throughout the study, 32 separate respirator wearers were identified and approached to schedule their annual or semi-annual fit test. As they were scheduled, their FF values from fit tests in 1993 were collected from past records. None of the employees switched brands or sizes of masks during that time. They were fit tested with their normally-worn mask and a sampling adapter or a mask of the same style and size with a permanent sampling probe, and were asked to participate in the part of the study involving the 9970. Of the 32 employees selected, there were 25 wearers for which a 1993 FF and 1994 FF value were available for analysis. Twenty-one matches of 1994 FF and 9970 FF were obtained. (See Table 1). One wearer did not have a 1993 FF value. Two wearers used full face respirators; so their 1993 and 1994 FF values were not included in the study, although they were fit tested with the 9970 and completed the questionnaire. Four other wearers were not able to be fit tested with their rubber half face masks, so were not included in the first part of the study. They were fit tested with the 9970 and completed the questionnaire, however. Two respirator wearers declined participation in the 9970 part of the study, and three who had agreed to participate were not able to be quantitatively fit tested with the 9970 because of their time constraints. Thirty respirator wearers completed the questionnaire. (See Table 2)

Chapter 6 Analysis of Results

6.1 Statistical Methods

The power of a good statistical test should be its ability to detect departures from the null hypothesis. For example, as in the first case, the null hypothesis stated that no change in FF values occurred between the two years, 1993 and 1994 and that, therefore, the mean of the differences is zero. The test is performed in the hope of showing that the null hypothesis is false. "Power" is the probability that a statistical test will reject the null hypothesis given that the null hypothesis is false. A fixed level of significance is assumed to be at 0.05. A matched-pairs t-test takes the difference within the matched pairs to make a single sample. This sample is then analyzed for its mean, standard deviation and p-value.

In order to show reliability of the fit factor data from year to year, the 1993 FF values for each person were matched to the 1994 FF values for the same person for the regular rubber half face masks using a matched pairs t-test.

The 1994 rubber half face mask FF values and the 9970 disposable half face mask FF values for each person were subtracted in order to determine the difference in FF values between the two masks when the tests are run within the same hour on the same day.

The mean value for each of the eight indices of performance listed on the questionnaire was calculated to determine the overall acceptance of the 9970 by the respirator wearer. The respondent could rate the mask from 1-5 in the eight different indices. These responses were averaged for each of the indices.

6.2 SAS

SAS is a software system which can be used to describe a collection of data and produce a variety of statistical analyses. It was run in MS-DOS on a microcomputer. The specific procedure used to analyze the data in this study combined descriptive statistics with

frequency distributions. This procedure, called PROC UNIVARIATE, can compute, among other things, the: number of observations; mean; standard deviation; variance; standard error of the mean; maximum; minimum; range; and, medium, upper and lower quartile ranges.

6.3 Results

An analysis was performed on the 1993 rubber half face mask FF values, 1994 rubber half face mask FF values and the 9970 disposable mask FF values (which were also collected in 1994). The mean and standard deviation are described in the table below.

	<u>1993</u>	<u>1994</u>	<u>9970</u>
N	27	26	27
Mean	1717	1148	752
Std Dev	2081	1824	932

Below are the frequency graphs for the three categories. All three graphs show a higher frequency at the lower fit factor values.

The data appear to be log-normally distributed. Assuming this, each FF category was analyzed to determine the median and geometric standard deviation. The 1993 FF data for the rubber half face masks had a median of 875 and a geometric standard deviation of 2.5. The 1994 FF data for the rubber half face masks had a median of 560 and a geometric standard deviation of 2.5. The 9970 FF data had a median of 300 and a geometric standard deviation of 3.3.

In order to show the reliability between the two years with the same mask, the matched-pairs test was performed on the data. There were 25 values after the 1994 values were subtracted from the 1993 values. (See Figures 4 and 5 for normal axes and log axes

graphs of 1993 v. 1994 FF values.) The null hypothesis stated that no change occurred between the two years and the mean of the differences should be zero. The mean was 658 with a standard deviation of 2769. The positive mean indicated that, on average, 1993 values were higher than 1994 values. However, a high p-value of 0.26 indicated that this value was not statistically significant different from zero. Thus, no significant difference in fit factor from year (1) to year (2) was found.

The linear regression was calculated for the 1994 FF values v. the 9970 FF values. (See Figures 6 and 7 for normal axes and log axes graphs of 1994 v. 9970 FF values.) A very low R-squared value of less than 3% was found. The differences between the 1994 rubber half face mask FF values and the 9970 FF values were taken and the histogram of the difference versus the frequency is shown below. The mean of the twenty-one differences was 214 and the standard deviation was 2241. Because the mean was positive and the 9970 values had been subtracted from the 1994 FF values, it can be said that on average the 1994 values are somewhat, but not significantly, higher than the 9970 values.

This graph also appears to be log-normal. This data was analyzed and a median of 580 and a geometric standard deviation of 2.4 was found.

The values for the thirty answered questionnaires were averaged to determine if the 9970 mask was more acceptable, the same or less acceptable in each category than the normally worn rubber half face masks. The averages or means were calculated based on the employees' perception of the 9970 versus their normally worn mask. The means are tabulated below. A mean of 3 would indicate that the employee felt the same about the 9970 versus their normally worn mask, a mean of 5 would indicate that they felt the 9970 was much more acceptable, and a mean of 1 would indicate that they felt the 9970 was much less acceptable.

<u>indices of performance</u>	<u>mean</u>
comfort	3.5
protection afforded	2.8
wear time	3.2
ease of putting on	3.2
ease of removal	3.1
fit to face	2.9
durability	2.0
applicability to respiratory protection needs	2.8

Of the eight indices of performance, only two showed ratings that were very different than 3. The 3M 9970 was rated higher in the comfort category. The employees perceived it to be more acceptable in terms of comfort than their normally-worn rubber half face mask. The 3M 9970 was rated lower in the durability category. The employees perceived it to be less acceptable in terms of durability than their normally-worn rubber half face mask.

Chapter 7 Discussion

7.1 Overview

From the data collected, all three categories of FF values showed a wide range of values. On average, the 1993 rubber half face mask FF values were higher than the 1994 rubber half face mask FF values and the 1994 rubber half face mask FF values were higher than the 9970 FF values (also collected in 1994). It could be said that, overall, the 3M disposable 9970 mask does not fit as well as the rubber half face masks because the average FF was less.

These results indicate that no significant change occurred between the 1993 FF values and 1994 FF values for the rubber half face masks. The R-squared value for the 1994 FF v. 9970 FF data was low (less than 3%), indicating no correlation between the rubber half face mask and the disposable, 9970 mask.

In general, the numbers show that FF values vary greatly between (1) a group of individuals wearing the same kind of mask, (2) from year to year on an individual wearing the same kind of mask and (3) from mask to mask worn by the same individual.

7.2 1993 versus 1994 FF Values for Rubber Half Face Masks

It was reassuring to find that the differences between the 1993 and 1994 FF values were not significant. Such differences that do exist can be explained qualitatively in a number of ways. Changes in face size, use of the in-facepiece adaptable sampling probe and smoking can all help explain the differences in the FF values.

Although the same style of mask was used for fit testing purposes in 1993 and 1994, differences in an individual's fit factor could occur due to changes in their facial shape or the amount of facial hair present at either time. A gain or loss of weight can significantly alter the way the facepiece of a mask seals to the face. Also dental or orthodontic work can alter facial structure. One study has shown that leakage can increase from 50 to 1000

times (thereby changing the fit factor) between day 0 (clean shaven) and day 9 of facial hair growth (Stobbe *et al.*, 1988). The 1993 fit test might have been performed on day 0 and the 1994 fit test on day 1 and a large difference might have been seen in the fit factors even if hair was not visible on their face (this would depend upon the person). This situation would be avoided by requiring all men to shave the day of the fit test; but even so, a few hours facial hair growth might make a difference on some people.

An in-facepiece removable sampling adapter probe was purchased during 1993. It allowed quantitative fit testing to be performed using the wearer's own mask. Some of the 1993 FF values most likely were obtained using this device while some were not. Only some of the 1994 FF values were obtained while using it. There is no record of these data. In a study performed to compare fit factors measured by using a permanent sampling probe with those measured using the removable sampling adapter probe, the difference between the two never exceeded ten percent (Johnson *et al.*, 1992). Because other studies have not been performed to confirm these results, a variation of greater than ten percent might be seen between using the in-facepiece removable sampling adapter probe and the permanent sampling probe. Perhaps this was a factor in the present work.

Smoking can affect FF values because it is believed that smokers exhale smoke for up to 30 minutes after smoking. The smoke particles are then sampled inside the respirator resulting in lowered measured fit factors (TSI, Inc., 1989). Because smoking was not monitored in the participants, it is unclear what role it played in affecting FF values.

7.3 1994 Rubber Half Face Masks versus 9970 Disposable Masks FF Values

Not every mask fits every respirator wearer in the same way. That is, there is no reason to expect a strong correlation between the performance of one respirator and another, especially if they are very different in configuration and type. This is borne out by the differences between the 1994 FF values and 9970 FF values. This is why an employer must offer many different brands, styles and sizes of respirators for their employees to choose from. Because the 1994 rubber half face mask fit tests and the 9970 fit tests were

performed on the same day within the same hour, differences in the FF values between these two are most likely inherent in their physical shape. The main reason for the differences could be variations in the seal of the facepiece to the wearer's face. The 9970 has approximately 1.5 inches of rubber for the facepiece seal attached to the HEPA filter. The rubber half face masks are completely rubber with a rounded edge for the facepiece seal and filter piece settings on the front for the filters and cartridges. The respirator's facepiece seal area is quite different between the two and could influence the overall fit and fit factor.

A study by Stobbe *et al.* (1988) showed that the effect on the fit factor from a beard was highly variable between respirators. This could be an explanation for differences in FF values for the same person between the rubber half face masks and the 9970 mask (Stobbe *et al.*, 1988).

7.4 Perceptions of the 9970

The 9970 was rated to be more acceptable than the wearer's normally-worn rubber half face masks in one area, comfort. This higher rating was most likely due to the lighter weight and less bulkiness of the 9970 compared to the rubber masks. This rating is important because respirator wearers may be more inclined to remove or not wear masks that are uncomfortable. This could, in turn, lead to excessive exposure to airborne contaminants. If an employee wears a respirator for a longer period exposure can be significantly lowered.

The participants rated the 9970 less acceptable than their normally-worn masks in durability. The lowered perceived durability could be because the mask is made solely of a filter and a two-inch strip of rubber.

No real preference was shown by the respondents regarding wear time, ease of putting on, ease of removal, protection afforded, applicability to respiratory protection needs and fit-to-face.

Chapter 8 Conclusions

This study has demonstrated that it is difficult to use one year's FF values to predict values for the next and from one style of mask to another, although the changes between FF values in this study were not significant. The fact that the FF values change from year to year appears to be a valid argument for testing at least annually or semi-annually. People and masks can change shape and a properly fitted respirator is needed for protection against airborne hazards. It has been shown that, for the same respirator, much variation will be seen and fit factors will not be constant on humans. This may be due to face seal leak size fluctuations (Krishnan *et al.*, 1994).

The discrepancies in the FF values from year to year and from mask to mask bring into some question of validity of the fit testing procedure. However, even though there were large differences between the 1993 and 1994 values, and also the 1994 and 1997 values, it is believed that the fit testing procedure is still a valid tool to determine if the mask adequately fits the wearer. It is valid because, in order to pass and be able to wear the respirator, a FF value of 100 must be achieved. This sets a minimum level of fit that must be achieved before the wearer can use the respirator. The majority of the fit factor values were indeed much higher than 100 and the differences from year to year that could be seen from the data (although not statistically significant) were taking place well above the 100 minimum mark.

Regulations require an employer to offer several brands of respirators to its employees in order to have respirators available that will achieve the best possible fit. Fit tests should be performed before any employee wears his/her respirator in a given aerosol exposure situation. At the fit testing time, the appropriate respirator can be chosen that has a good fit, is comfortable to the wearer and allows a FF value of 100 or greater to be achieved (for half face masks). The laboratory could offer the use of the 1997 mask because it does fit some people above the FF of 100 mark, is comfortable and is easy and convenient to use. Because each person is fit tested individually, the overall lower FF values for the

9970 found in this study can be overlooked when trying to decide which masks to offer employees. If a person does not achieve a FF of 100 with the 9970, then he/she would not be allowed to wear that mask. No matter what new masks the institution decides to use, a fit test must be performed for each wearer.

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1910.134 -- RESPIRATORY PROTECTION

(a) Permissible practice.

(1) In the control of those occupational diseases caused by breathing air contaminated with harmful dusts, fogs, fumes, mists, gases, smokes, sprays, or vapors, the primary objective shall be to prevent atmospheric contamination. This shall be accomplished as far as feasible by accepted engineering control measures (for example, enclosure or confinement of the operation, general and local ventilation, and substitution of less toxic materials). When effective engineering controls are not feasible, or while they are being instituted, appropriate respirators shall be used pursuant to the following requirements.

(2) Respirators shall be provided by the employer when such equipment is necessary to protect the health of the employee. The employer shall provide the respirators which are applicable and suitable for the purpose intended. The employer shall be responsible for the establishment and maintenance of a respiratory protective program which shall include the requirements outlined in paragraph (b) of this section.

(3) The employee shall use the provided respiratory protection in accordance with instructions and training received.

(b) Requirements for a minimal acceptable program.

(1) Written standard operating procedures governing the selection and use of respirators shall be established.

(2) Respirators shall be selected on the basis of hazards to which the worker is exposed.

(3) The user shall be instructed and trained in the proper use of respirators and their limitations.

(4) [Reserved]

(5) Respirators shall be regularly cleaned and disinfected. Those used by more than one worker shall be thoroughly cleaned and disinfected after each use.

(6) Respirators shall be stored in a convenient, clean, and sanitary location.

(7) Respirators used routinely shall be inspected during cleaning. Worn or deteriorated parts shall be replaced. Respirators for emergency use such as self-contained devices shall be thoroughly inspected at least once a month and after each use.

(8) Appropriate surveillance of work area conditions and degree of employee exposure or stress shall be maintained.

(9) There shall be regular inspection and evaluation to determine the continued effectiveness of the program.

(10) Persons should not be assigned to tasks requiring use of respirators unless it has been determined that they are physically able to perform the work and use the equipment. The local physician shall determine what health and physical conditions are pertinent. The respirator user's medical status should be reviewed periodically (for instance, annually).

(11) Respirators shall be selected from among those jointly approved by the Mine Safety and Health Administration and the National Institute for Occupational Safety

and Health under the provisions of 30 CFR part 11.

(c) Selection of respirators.

Proper selection of respirators shall be made according to the guidance of American National Standard Practices for Respiratory Protection Z88.2-1969.

(d) Air quality.

(1) Compressed air, compressed oxygen, liquid air, and liquid oxygen used for respiration shall be of high purity. Oxygen shall meet the requirements of the United States Pharmacopoeia for medical or breathing oxygen. Breathing air shall meet at least the requirements of the specification for Grade D breathing air as described in Compressed Gas Association Commodity Specification G-7.1-1966. Compressed oxygen shall not be used in supplied-air respirators or in open circuit self-contained breathing apparatus that have previously used compressed air. Oxygen must never be used with air line respirators.

(2) Breathing air may be supplied to respirators from cylinders or air compressors.

(i) Cylinders shall be tested and maintained as prescribed in the Shipping Container Specification Regulations of the Department of Transportation (49 CFR Part 178).

(ii) The compressor for supplying air shall be equipped with necessary safety and standby devices. A breathing air-type compressor shall be used. Compressors shall be constructed and situated so as to avoid entry of contaminated air into the system and suitable in-line air purifying sorbent beds and filters installed to further assure breathing air quality. A receiver of sufficient capacity to enable the respirator wearer to escape from a contaminated atmosphere in event of compressor failure, and alarms to indicate

compressor failure and overheating shall be installed in the system. If an oil-lubricated compressor is used, it shall have a high-temperature or carbon monoxide alarm, or both. If only a high-temperature alarm is used, the air from the compressor shall be frequently tested for carbon monoxide to insure that it meets the specifications in paragraph (d)(1) of this section.

(3) Air line couplings shall be incompatible with outlets for other gas systems to prevent inadvertent servicing of air line respirators with nonrespirable gases or oxygen.

(4) Breathing gas containers shall be marked in accordance with American National Standard Method of Marking Portable Compressed Gas Containers to Identify the Material Contained, Z48.1-1954; Federal Specification BB-A-1034a, June 21, 1968, Air, Compressed for Breathing Purposes; or Interim Federal Specification GG-B-00675b, April 27, 1965, Breathing Apparatus, Self-Contained.

(e) Use of respirators.

(1) Standard procedures shall be developed for respirator use. These should include all information and guidance necessary for their proper selection, use, and care. Possible emergency and routine uses of respirators should be anticipated and planned for.

(2) The correct respirator shall be specified for each job. The respirator type is usually specified in the work procedures by a qualified individual supervising the respiratory protective program. The individual issuing them shall be adequately instructed to insure that the correct respirator is issued.

(3) Written procedures shall be prepared covering safe use of respirators in dangerous atmospheres that might be encountered in normal operations or in emergencies. Personnel shall be familiar with these procedures and the available respirators.

(i) In areas where the wearer, with failure of the respirator, could be overcome by a toxic or oxygen-deficient atmosphere, at least one additional man shall be present. Communications (visual, voice, or signal line) shall be maintained between both or all individuals present. Planning shall be such that one individual will be unaffected by any likely incident and have the proper rescue equipment to be able to assist the other(s) in case of emergency.

(ii) When self-contained breathing apparatus or hose masks with blowers are used in atmospheres immediately dangerous to life or health, standby men must be present with suitable rescue equipment.

(iii) Persons using air line respirators in atmospheres immediately hazardous to life or health shall be equipped with safety harnesses and safety lines for lifting or removing persons from hazardous atmospheres or other and equivalent provisions for the rescue of persons from hazardous atmospheres shall be used. A standby man or men with suitable self-contained breathing apparatus shall be at the nearest fresh air base for emergency rescue.

(4) Respiratory protection is no better than the respirator in use, even though it is worn conscientiously. Frequent random inspections shall be conducted by a qualified individual to assure that respirators are properly selected, used, cleaned, and maintained.

(5) For safe use of any respirator, it is essential that the user be properly instructed in its selection, use, and maintenance. Both supervisors and workers shall be so instructed by competent persons. Training shall provide the men an opportunity to handle the respirator, have it fitted properly, test its face-piece-to-face seal, wear it in normal air for a long familiarity period, and, finally, to wear it in a test atmosphere.

(i) Every respirator wearer shall receive fitting instructions including demonstrations

and practice in how the respirator should be worn, how to adjust it, and how to determine if it fits properly. Respirators shall not be worn when conditions prevent a good face seal. Such conditions may be a growth of beard, sideburns, a skull cap that projects under the facepiece, or temple pieces on glasses. Also, the absence of one or both dentures can seriously affect the fit of a facepiece. The worker's diligence in observing these factors shall be evaluated by periodic check. To assure proper protection, the facepiece fit shall be checked by the wearer each time he puts on the respirator. This may be done by following the manufacturer's facepiece fitting instructions.

(ii) Providing respiratory protection for individuals wearing corrective glasses is a serious problem. A proper seal cannot be established if the temple bars of eye glasses extend through the sealing edge of the full facepiece. As a temporary measure, glasses with short temple bars or without temple bars may be taped to the wearer's head. Wearing of contact lenses in contaminated atmospheres with a respirator shall not be allowed. Systems have been developed for mounting corrective lenses inside full facepieces. When a workman must wear corrective lenses as part of the facepiece, the facepiece and lenses shall be fitted by qualified individuals to provide good vision, comfort, and a gas-tight seal.

(iii) If corrective spectacles or goggles are required, they shall be worn so as not to affect the fit of the facepiece. Proper selection of equipment will minimize or avoid this problem.

(f) Maintenance and care of respirators.

(1) A program for maintenance and care of respirators shall be adjusted to the type of plant, working conditions, and hazards involved, and shall include the following basic services:

(i) Inspection for defects (including a leak check),

(ii) Cleaning and disinfecting,

(iii) Repair,

(iv) Storage

Equipment shall be properly maintained to retain its original effectiveness.

(2) (i) All respirators shall be inspected routinely before and after each use. A respirator that is not routinely used but is kept ready for emergency use shall be inspected after each use and at least monthly to assure that it is in satisfactory working condition.

(ii) Self-contained breathing apparatus shall be inspected monthly. Air and oxygen cylinders shall be fully charged according to the manufacturer's instructions. It shall be determined that the regulator and warning devices function properly.

(iii) Respirator inspection shall include a check of the tightness of connections and the condition of the facepiece, headbands, valves, connecting tube, and canisters. Rubber or elastomer parts shall be inspected for pliability and signs of deterioration. Stretching and manipulating rubber or elastomer parts with a massaging action will keep them pliable and flexible and prevent them from taking a set during storage.

(iv) A record shall be kept of inspection dates and findings for respirators maintained for emergency use.

(3) Routinely used respirators shall be collected, cleaned, and disinfected as frequently as necessary to insure that proper protection is provided for the wearer. Respirators maintained for emergency use shall be cleaned and disinfected after each use.

(4) Replacement or repairs shall be done only by experienced persons with parts designed for the respirator. No attempt shall be made to replace components or to make

adjustment or repairs beyond the manufacturer's recommendations. Reducing or admission valves or regulators shall be returned to the manufacturer or to a trained technician for adjustment or repair.

(5) (i) After inspection, cleaning, and necessary repair, respirators shall be stored to protect against dust, sunlight, heat, extreme cold, excessive moisture, or damaging chemicals. Respirators placed at stations and work areas for emergency use should be quickly accessible at all times and should be stored in compartments built for the purpose. The compartments should be clearly marked. Routinely used respirators, such as dust respirators, may be placed in plastic bags. Respirators should not be stored in such places as lockers or tool boxes unless they are in carrying cases or cartons.

(ii) Respirators should be packed or stored so that the facepiece and exhalation valve will rest in a normal position and function will not be impaired by the elastomer setting in an abnormal position.

(iii) Instructions for proper storage of emergency respirators, such as gas masks and self-contained breathing apparatus, are found in "use and care" instructions usually mounted inside the carrying case lid.

(g) Identification of gas mask canisters.

(1) The primary means of identifying a gas mask canister shall be by means of properly worded labels. The secondary means of identifying a gas mask canister shall be by a color code.

(2) All who issue or use gas masks falling within the scope of this section shall see that all gas mask canisters purchased or used by them are properly labeled and colored in accordance with these requirements before they are placed in service and that the labels and colors are properly maintained at all times thereafter until the canisters have completely served their purpose.

(3) On each canister shall appear in bold letters the following:

(i) -

Canister for _____
(Name for atmospheric contaminant)

or

Type N Gas Mask Canister

(ii) In addition, essentially the following wording shall appear beneath the appropriate phrase on the canister label: "For respiratory protection in atmospheres containing not more than _____ percent by volume of

(Name of atmospheric contaminant)

(4) Canisters having a special high-efficiency filter for protection against radionuclides and other highly toxic particulates shall be labeled with a statement of the type and degree of protection afforded by the filter. The label shall be affixed to the neck end of, or to the gray stripe which is around and near the top of, the canister. The degree of protection shall be marked as the percent of penetration of the canister by a 0.3-micron-diameter dioctyl phthalate (DOP) smoke at a flow rate of 85 liters per minute.

(5) Each canister shall have a label warning that gas masks should be used only in atmospheres containing sufficient oxygen to support life (at least 16 percent by volume), since gas mask canisters are only designed to neutralize or remove contaminants from the air.

(6) Each gas mask canister shall be painted a distinctive color or combination of colors indicated in Table I-1. All colors used shall be such that they are clearly identifiable by the user and clearly distinguishable from one another. The color coating used shall offer a high degree of resistance to chipping, scaling, peeling, blistering, fading, and the effects of the ordinary atmospheres to which they may be exposed under normal conditions

of storage and use. Appropriately colored pressure sensitive tape may be used for the stripes.

Table I-1

Atmospheric Contaminants to be Protected Against	Colors Assigned •
Acid gases	White
Hydrocyanic acid gas	White with 1/2-inch green stripe completely around the canister near the bottom.
Chlorine gas	White with 1/2-inch yellow stripe completely around the canister near the bottom.
Organic vapors	Black
Ammonia gas	Green
Acid gases and ammonia gases	Green with 1/2-inch white stripe completely around the canister near the bottom
Carbon Monoxide	Blue
Acid gases and organic vapors	Yellow
Hydrocyanic acid gas and chloropicrin vapor	Yellow with 1/2-inch blue stripe completely around the canister near the bottom
Acid gases, organic vapors, and ammonia gases	Brown
Radioactive materials, excepting tritium and noble gases	Purple (Magenta):
Particulates (dusts, fumes, mists, fogs, or smokes) in combination with any of the above gases or vapors	Canister color for contaminant, as designated above with 1/2-inch gray stripe completely around the canister near the top.
All of the above atmospheric contaminants	Red with 1/2-inch gray stripe completely around the canister near the top.

- Gray shall not be assigned as a main color for a canister designed to remove acids or vapors.

NOTE: Orange shall be used as a complete body, or stripe color to represent gases not included in this table. The user will need to refer to the canister label to determine the degree of protection the canister will afford.

Appendix B

COMPARE THE 9970 TO YOUR PRESENT HALF-FACE RESPIRATOR

For the items below, indicate the acceptability of the 9970 in comparison to your present half mask respirator. Circle a "1" for a given item if the 9970 is much less acceptable; circle a "5" if the 9970 is much more acceptable:

		<u>Acceptability Index</u>				
		<u>Much</u> <u>Less</u>		<u>The</u> <u>Same</u>		<u>Much</u> <u>More</u>
1.	COMFORT	1	2	3	4	5
2.	PROTECTION	1	2	3	4	5
3.	WEAR TIME	1	2	3	4	5
4.	EASE PUTTING ON	1	2	3	4	5
5.	EASE TAKING OFF	1	2	3	4	5
6.	FIT TO MY FACE	1	2	3	4	5
7.	DURABLE	1	2	3	4	5
8.	FITS THE RESPIRATORY PROTECTION NEEDS OF MY WORKPLACE	1	2	3	4	5
9.	COMMENTS?					

NAME: _____

DATE: _____

Table 1: 1993, 1994, 9970 FF Values

Participant	1993 FF value	1994 FF value	9970 FF value
1	326	60	109
2	229	N/A	1160
3	1250	1320	1820
4	1240	692	934
5	N/A	N/A	20
6	302	345	3214
7	1340	185	34
8	314	N/A	251
9	856	306	2030
10	1580	588	283
11	1790	1520	11.5
12	1350	662	2000
13	981	98.7	118
14	665	2190	384
15	848	1430	708
16	862	478	103
17	642	1770	1860
18	230	302	264
19	1630	235	135
20	4350	106	2900
21	368	142	21
22	N/A	N/A	164
23	N/A	N/A	274
24	N/A	N/A	430
25	N/A	364	N/A
26	395	355	N/A
27	2920	1170	N/A
28	5230	4920	N/A
29	726	532	N/A
30	8760	788	158
31	883	8620	46
32	6290	659	872

Table 2: Participant Ratings of the Eight Indices of Performance for the 9970 Mask

<u>Participant</u>	<u>A</u>	<u>B</u>	<u>C</u>	<u>D</u>	<u>E</u>	<u>F</u>	<u>G</u>	<u>H</u>
1	4	3	4	3	3	4	2	1
2	5	2	4	3	3	3	2	3
3	2	3	2	2	3	3	1	3
4	3	2	3	2	2	2	4	3
5	4	1	4	5	5	3	1	2
6	2	3	3	3	4	2	2	3
7	3	3	2	3	3	2	2	1
8	3	3	2	3	3	3	3	3
9	2	3	3	4	3	3	2	3
10	2	3	2	3	3	3	2	3
11	4	2	1	2	2	2	1	1
12	5	2	3	2	3	2	2	3
13	4	3	4	5	5	5	3	3
14	4	3	3	4	3	3	2	3
15	5	3	5	4	4	2	1	3
16	4	4	2	4	4	3	1	4
17	4	3	5	3	3	5	3	5
18	5	3	5	4	3	4	1	3
19	4	3	3	3	2	3	1	3
20	4	3	3	4	3	3	3	3
21	2	2	3	3	3	2	2	2
22	4	3	3	3	3	4	3	3
23	5	3	5	3	3	3	2	5
24	4	1	4	1	5	1	1	1
25	1	2	2	3	2	1	1	2
26	2	3	3	3	3	3	3	3
27	4	3	4	3	3	3	2	3
28	declined participation							
29	declined participation							
30	4	3	4	3	3	4	2	1
31	2	2	1	3	3	1	2	2
32	5	3	5	5	4	3	2	3

A = Comfort

B = Protection Afforded

C = Wear time

D = Ease of putting on

E = Ease of removal

F = Fit to face

G = Durability

H = Applicability to respiratory protection needs

Figures 1, 2, and 3 Curves of Aerosol Fractions

Inhalable
Curve

Thoracic
Curve

Respirable
Curve

Figure 4 1993 v. 1994 FF Values (Log Axes)

Figure 5 1993 v. 1994 FF Values (Normal Axes)

Figure 6 1994 v. 19970 FF Values (Log Axes)

Figure 7 1994 v. 19970 FF Values (Normal Axes)