

DETERMINING AND VALIDATING THE ADEQUACY OF AIR-PURIFYING RESPIRATORS USED IN INDUSTRY

Part II—Development of a New Respirator Fit Test

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Abstract

A new type of respirator fit test has been developed which uses light as the test agent. Photosensitive paper is loaded into a respirator which is then worn by a test subject. Light is directed at the sealing surfaces of the respirator and facepiece leakage is evaluated when the photographic paper is developed. Two separate studies were conducted comparing this test to quantitative and saccharin fit tests. Results indicated that the photographic fit test rejected subjects wearing half-masks who obtained fit factors below 100. Results also indicated general agreement with the saccharin test, although the photographic test passed more subjects than the saccharin test. The photographic fit test described in this paper is inexpensive and simple to operate, results in a permanent record of the fit test, and can determine the exact location of facepiece leakage. A number of modifications to the present system are required to make it useful as a routine test for fitting employees in general industry. Also, further testing is required with a larger number of test subjects to validate the effectiveness of the test procedure.

Introduction

This is the second of a two-part paper describing Olin Corporation's efforts to evaluate and improve respirators used by its employees. In Part I, the results from a workplace protection factor study of maintenance employees using disposable air-purifying respirators for protection against elemental mercury were presented. This paper will describe the development of a radically new type of respirator fit test which uses light as the challenge agent.

Respirator fit tests fall into two main categories: those used for selecting respirators, and field tests for determining that respirators have been put on properly. This paper will concern itself only with respirator selection fit tests, which in turn can be classified into either qualitative or

quantitative tests. Qualitative fit tests (QLFTs) involve exposing a subject to a test concentration of an agent which can elicit a sensory response, usually either taste or smell. Results are totally dependent upon an accurate response from the subject. These tests are inexpensive and easy to administer, which makes them the most prevalent type of testing done by general industry. QLFTs do not indicate the precise degree to which a respirator can fit the face of the wearer, and are simply a method of selecting good from bad fitting respirator facepieces.

A quantitative fit test (QNFT), is a method for quantifying the fit of a facepiece to the wearer. To perform a QNFT, a subject is placed into a test chamber while wearing a respirator which

has been modified to allow air to be sampled from inside the facepiece. A low-toxicity contaminant is generated, and the contaminant is monitored both in the chamber and inside the facepiece. Results are calculated as a fit factor (FF), which is the ratio of the contaminant concentration in the booth to that inside the facepiece. QNFT instrumentation is sensitive enough to detect FFs of 10,000 or greater (Dynatech Frontier, 1982). Typical test equipment costs in excess of \$10,000 and requires a trained technician to both operate and maintain the equipment. Because of the cost associated with QNFT, general industry has been reluctant to routinely use it in spite of its technical superiority to QLFT.

Both types of fit testing have similar inherent drawbacks to them. Since only facepiece leakage is of interest, air-purifying respirators must be able to stop the test agent from entering the facepiece through the device's inlet. This is a serious limitation when working with respirators with a filter or sorbent, which cannot remove the fit test contaminant and which is built into the body of the respirator. A second drawback is that neither type of test indicates where leakage from the facepiece is occurring. This would be useful information to the respirator manufacturers for improving their devices and to the user for understanding what type and size respirator would best fit them without having to test each specific model.

The purpose of this study was to attempt to develop a new respirator fit test with the following features:

1. Use low-cost, readily available test equipment.
2. Use a low-toxicity test agent.
3. Require one to two minutes to complete.

4. Result in an objective determination of facepiece leakage.

Development of a Photographic Fit Test

Concerns with challenge agent toxicity lead to the conclusion that a successful test agent must be of low toxicity. The use of physical rather than chemical agents was considered. The possibility of using light as the challenge agent was explored. A fit test which operated like a camera was envisioned. A respirator would be loaded with photosensitive material, and then worn by a subject. The sensitivity of the test could be governed by three items: intensity of the light used as a challenge agent, test duration, and film sensitivity. It was encouraging that since the intensity of the light used and the film sensitivity could be easily altered in orders of magnitude, there were excellent possibilities for finding an appropriate combination for a fit test.

Months of experimenting with these variables was conducted in the company's darkroom, with the assistance of a staff photographer. A number of interesting items were determined during our testing. Since light travels in a straight line, in the case of typical half-mask respirators with a double sealing surface the inner sealing surfaces of a respirator need to be covered with a photosensitive material. The advantages of doing this is that the exact location of facepiece leakage can be determined. One problem encountered is that light can be transmitted through chemical cartridges and filters. Fortunately this leakage results in a very distinguishable pattern far different from facepiece leakage. The same problem occurred with disposable particulate respirators, requiring the use of less photosensitive material to measure facepiece leakage.

Materials and Methods

The purpose of this study was to compare the results of both qualitative and quantitative fit testing with a photographic fit test. The first testing was done at a chemical plant where quantitative fit testing is routinely performed. A small laboratory room was made suitable for the photographic testing by covering up windows where light could enter the room. Portable photographic safe lights, which filter out blue light, were set up in the room.

Kodachrome II® medium-contrast, resin-coated paper was cut to fit various sized Norton 7500 half-masks. This was done by hand using the

inner sealing surface of the respirator as a template. Two half-inch wide strips were placed inside the respirator against the inner sealing surfaces.

The following procedure was used for fit testing employees:

1. A test subject entered the room and received a brief explanation as to the purpose of the study and test procedures.
2. The lights in the room were turned off and photographic safe lights turned on. A Norton 7500 half-mask respirator was fitted with Kodak Kodachrome® II medium-contrast photographic

paper. The paper was placed in the respirator in a manner that did not interfere with the fit of the respirator.

3. The respirator was then put on and adjusted by the test subject.
4. A portable high-intensity white light source (250 W) was turned on and moved around the sealing surfaces of the respirator, approximately 6-12 inches from the subjects' faces. The subjects closed their eyes and moved their heads slowly up and down and side to side for one minute.
5. The light was then shut off, the film taken out and placed in an envelope identified with the employee's name and respirator size.

After the test subject left the room, the room lights were again shut off and the photographic paper developed. The paper was placed in a developing tray containing a one-to-two dilution of Dektol® developer. After one to two minutes, the paper was transferred to a solution of Kodak Stop Bath and after 10-15 seconds to a solution of Kodak Fixer. The paper stayed in the Fixer for 5-10 minutes, and then was thoroughly washed with water and dried on a blotter. Plastic tongs were used to transfer the paper from one bath to another; this minimizes oily fingerprints on the paper. An adequate time in the Fixer bath is critical, if the fit test photos are to be preserved for any length of time.

Two sizes of Norton 7500 respirators were tested per subject. The subjects then underwent a

QNFT which was located at a different site within the plant. The same two-size respirators were worn by subjects during QNFT. The following exercises were performed during fit testing: normal breathing, deep breathing, moving their heads side to side, moving their heads up and down, normal talking, and a repeat of normal breathing.

A second study was conducted at an Olin facility using the same disposable mercury air-purifying respirator described in the previous paper. Photographic fit tests were conducted with nine employees using procedures previously described. One difference was that a less-sensitive photographic paper, Kodak AZO grade one, was used. The other difference was that because the disposable respirator did not have an inner sealing surface, a circular piece of paper was cut and attached to the center of the respirator. Again, this did not affect the way in which the respirator sealed to the face.

After employees were photographically fit-tested, they were tested using the 3M FT-10 saccharin fit-test procedure (Federal Register, 1981). This included prescreening employees to determine their ability to detect saccharin, then using a one hundred times more concentrated aerosol as the test agent. The saccharin test was slightly modified, so that subjects who did not detect saccharin after ten squeezes of the nebulizer (instead of 30) were eliminated from the test.

Results

The results of QNFT and photographic fit testing are displayed in Table 1. All eight test subjects who volunteered were supervisory personnel familiar with the use of respirators, but they were not routine users. A single individual administered all the photographic fit tests to maintain consistency from one test to another. A different individual performed all the QNFTs and was unaware of the results of photographic fit testing previously performed to minimize biasing of the results. Each subject was fit tested with two different size Norton 7500 respirators. One size was intended to offer an excellent fit, and the other to give a poor facepiece fit.

The protection factors obtained from QNFTs were calculated by averaging the peak penetration of all six exercises. The best fitting respirators resulted in FFs ranging from 66-6,000 with a geometric mean of 578. FFs of poor fitting respirators ranged from 2-8 with a geometric mean of 3. Results from the photographic fit tests were quali-

tatively assessed after the photographic paper was developed. The degree and location of facepiece leakage, resulting in the paper changing from white to grey or black, was noted. An adequate fit was determined when the paper was totally white (no exposure), or when a small light grey area developed. A fit test was ruled a failure when either a dark black spot developed on the paper, or when a grey area covered more than 5-10% of the total surface area of the paper. Subjects who passed the photographic fit test had corresponding FFs ranging from 166-6,000 with a geometric mean of 787. Those subjects failing the photographic fit test had corresponding FFs of 2-66 with a geometric mean of 4. The photographic fit test appeared to have a cutoff for accepted and rejected fits of an FF between 66-166. A typical photograph resulting from a fit test is shown in Fig. 1.

A few aspects of the testing should be kept in mind when reviewing the results. The test protocol required that respirators be put on and taken off

TABLE I
Comparison of Photographic Fit Test
and Quantitative Fit Test Data

Norton 7500 Respirator

<u>Test Subject</u>	<u>Respirator Size</u>	<u>Quant. FF</u>	<u>Photographic Test</u>	<u>Comments</u>
A	M	166	Passed	small leak by chin
	L	3	Failed	large leak by chin
B	S	8	Failed	moderate leakage
	M	166	Passed	minor leak by chin
C	M	281	Passed	no leakage
	L	3	Failed	moderate leakage by right cheek
D	M	6000	Passed	small leak at nose
	L	2	Failed	tremendous leak by nose
E	M	2500	Passed	no leakage
	L	2	Failed	moderate leak by nose
F	M	1382	Passed	minor leakage
	L	2	Failed	large leak by nose
G	S	1170	Passed	no leakage
	M	2	Failed	large leak
H	M	66	Failed	significant leakage
	L	3	Failed	significant leakage

after each test. Variation in the way respirators were put on for each test probably resulted in inconsistencies in the data. For example, test subject C had an FF of 281 and no detectable leakage based on the photographic test. Test subject D had an FF of 6,000 with a minor leak at the nose detected by the photographic method. Another issue to consider is that the small number of test subjects did not allow for a meaningful statistical treatment of the data. Results should be viewed as an encouraging preliminary evaluation of the photographic test method.

The results comparing saccharin and photographic fit testing are displayed in Table 2. Nine subjects volunteered to be fit tested wearing disposable mercury air-purifying respirators. All subjects were routine users of the devices. Workplace protection factors, discussed in Part I of this study, are displayed in Table 2 for comparison purposes. As with the QNFT tests, a single individual adminis-

tered all the photographic fit tests for consistency. A different individual performed the saccharin testing and was unaware of the results of photographic fit testing to minimize biasing of the results.

Four test subjects passed the saccharin fit test, four failed the test, and one was insensitive to the solution. All four subjects passing the saccharin fit test also passed the photographic fit test. Three subjects, who failed the saccharin test after detecting a slight sweetness, passed the photographic test. Interestingly, the two subjects who failed the photographic fit test had the lowest workplace protection factors of the group.

The same comments which applied to the QNFT tests apply to these results as well. Individuals put on and took off respirators after each test resulting in some variability in the fit of the respirator from one test to another. The pass/fail criteria used for this test was slightly different because of differences in the sensitivity of the photographic

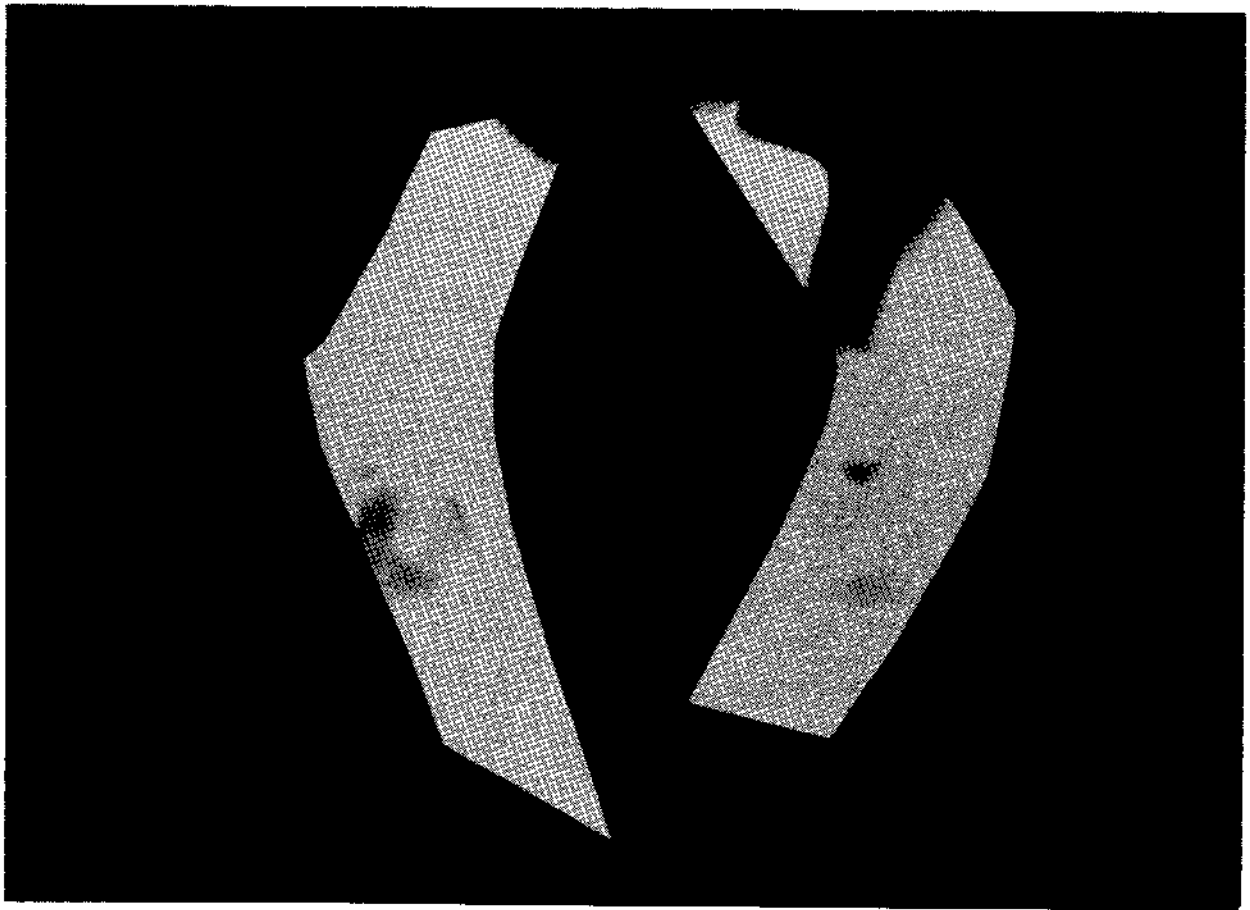


Figure 1. Example of respirator leak at the chin on a reusable respirator measured by photographic fit test.

paper. A subject was considered to have an adequate respirator fit unless a dark black spot developed on the paper. Subject A had significant leakage at the chin. The subject was retested about four hours after the first test. Figure 2 shows the results of these tests. A nearly identical exposure pattern occurred with only slight differences in the intensity of the exposure. This is an encouraging indication as to the repeatability of this test.

Discussion

Respirator fit testing has been actively investigated during the past two decades. The use of isoamyl acetate and irritant smoke as qualitative test agents appears in the 1969 ANSI, "Practices for Respiratory Protection" (1969). A number of recent studies have examined the correlation between qualitative and quantitative fit tests. Typically, these studies have had individuals don a respirator and receive a QLFT and QNFT sequentially, without altering the fit of the facepiece. Revoir reported the

comparison of isoamyl acetate (IAA) testing with QNFT results for half-mask respirators (1983). This study found IAA tests to reject all subjects with FFs below 10. However, 25 percent of the subjects who obtained FFs above 100 were also rejected. Marsh reported that the irritant smoke test was 100 percent effective in rejecting subjects with FFs below 10 (1984). Unfortunately, 20 percent of the subjects who had FFs above 100 were also rejected. Similar results have been reported by Marsh comparing the saccharin fit test with QNFT results (1984). The saccharin test was 100% effective in rejecting test subjects with FFs below 10; however, the test also rejected 60 percent of the subjects who obtained FFs above 100. A major study correlating three QLFTs with QNFTs was reported by Hardis (1983). This study examined both half-mask and full facepiece respirators using the negative pressure test, the IAA test, and the irritant smoke test. All three tests were highly effective and rejected over 99% of the devices with FFs below 10 for a half-mask respirator. The authors concluded

TABLE II
Comparison of Photographic Fit Test
and Saccharin Fit Test Data

3M Modified 9908 Respirator

<u>Employee</u>	<u>Saccharin</u>	<u>Photographic</u>	<u>Workplace PF *</u>	<u>Comments</u>
A	Failed (slight detection)	Failed	19.9	large leak by chin
B	Failed (slight detection)	Passed	35.8	no leak
C	Failed	Passed	27.5	small leak by chin
D	Passed	Passed	21.1	small leakage
E	Failed (slight detection)	Passed	39.0	small leak by right cheek
F	N.A. ¹	Failed	18.8	leak by right cheek
G	Passed	Passed	-	minor leakage
H	Passed	Passed	-	no leak
I	Passed	Passed	-	no leak

¹Could not detect Saccharin

*Uncorrected

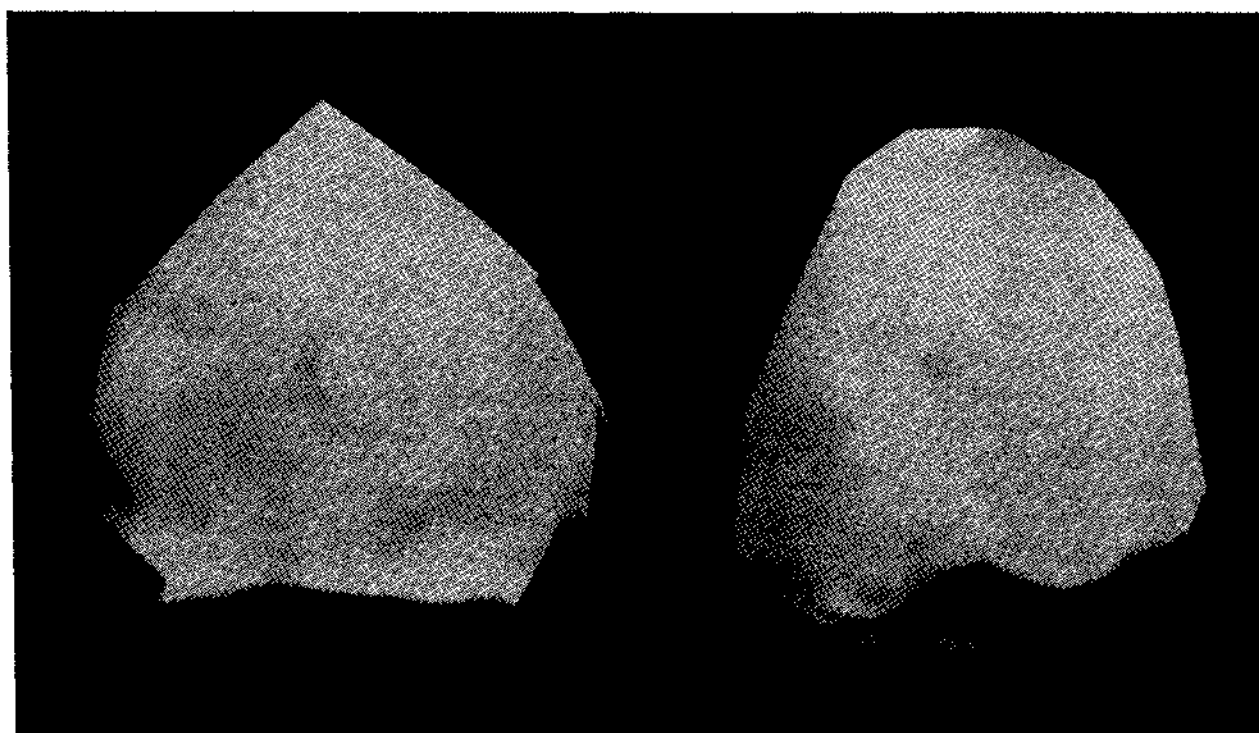


Figure 2. Results of photographic fit testing of a disposable respirator indicating a large leak at the chin.

that the irritant smoke test appeared to be superior to the other two, as it elicited a less subjective response from the test subject, and the experimental data showed a dose-response relationship.

Recently, there have been attempts to standardize the test conditions of QLFTs. A major study examining IAA was undertaken by Nelson et al. (1984). This study developed a method for pre-screening subjects to determine that their odor threshold was one part per million (ppm) or lower. An inexpensive test booth was also described in the study, whereby subjects were challenged to a test concentration of approximately 150 ppm of IAA. Theoretically, individuals who pass this test would have an FF of 150 or greater. Test results comparing this IAA test to QNFT results indicated that the test was nearly 100% effective in rejecting subjects with FFs below 100. The lowest FF of a subject who passed the test was 95.

All these studies indicate that available QLFTs are capable of rejecting a very high percentage of individuals with poor fitting respirators based on the ANSI criteria of 10 for a half-mask facepiece (1980). However, these tests will also reject a high proportion of subjects with adequately fitting respirators, because of the need to have a safety factor typically of ten built into the test. This is an economic burden to the employer who must spend additional costs performing unnecessary fit tests. Additionally, it may cause a burden on the employee, if only a single size respirator is available, which is typical for disposable devices. An individual may be forced to use a less desirable multi-size respirator, even when the single size disposable device offers adequate protection.

There is concern among some respirator program administrators that subjects will not always give a true response to the fit test agent if it requires a voluntary sensory response. This is one reason why the irritant-smoke QLFT remains popular. Unfortunately, the test administrator cannot always be sure of the ability of the smoke to cause an involuntary response at a low concentration. The administrator may also be unwilling to prescreen test subjects to high concentrations of irritant smoke resulting in undesirable choking of the subject.

Another drawback to QLFTs are that sensory responses vary greatly. Amoore has recently done a study examining available odor threshold data (1983). He found that odor thresholds to chemicals were log-normally distributed among individuals indicating wide variations. Additionally, he found

that an individual's odor threshold to a given substance can vary widely from day to day. Therefore, a drawback to QLFTs that requires a sensory response is that the actual safety factor built into the test is unknown.

Quantitative fit tests, unlike QLFTs, can indicate the precise leakage of a respirator. One of the early attempts at QNFT used Freon gas as the test agent (Adley, 1962). This was a novel approach which used low-cost test equipment and had excellent sensitivity. The modern day commercial QNFT units are based on the work done at the Los Alamos National Laboratory for the Department of Energy. These are expensive and sophisticated units, originally designed to assure workers a high degree of reliability, when wearing a respirator for protection against radionuclides. Hyatt developed the concept of protection factors while working on this project (1976). Willeke has recently published information indicating that a condensation nuclei counter detector allows for the use of a wider variety of challenge contaminants than does the light-scattering photometer used in most commercial QNFT units (1981).

The problem with QNFT units presently available is that they are inappropriate to the needs of general industry. Most industrial respirator applications involve exposure to a low to moderately toxic contaminant at concentrations frequently below ten times a recognized safe exposure level (TLV or PEL). There have been no successful innovative attempts to produce a simple low cost QNFT capable of determining FFs in the 100-1,000 range.

An initial effort made by the author at developing a new fit test involved the use of color-indicating, paper-tape passive dosimeters. Color-indicating paper tape is paper that has been treated with chemicals to allow a reaction to occur resulting in a color change. The initial system was designed to have paper tape inside and outside a respirator worn by a test subject. After exposure to a test agent, the two papers could be examined either semi-quantitatively with a color chart, or quantitatively with a densitometer, to determine the protection factor of the device.

One requirement for using such a system is that the tape be extremely sensitive. Tape systems available are not well suited for this purpose. They typically are available for highly reactive chemicals such as toluene diisocyanate, phosgene, and chlorine. These chemicals are too toxic to be suitable as fit test agents. Further research into this area might prove fruitful in developing a semi-quantitative respirator fit test system.

Conclusions

The results of this study indicate that a fit test system which uses light as the challenge agent may be a viable alternative to available QLFT methods.

This test is inexpensive, does not require a subjective response from the user, can detect the exact location of respirator leakage, and results in a permanent record of the test in the form of a photograph.

The test method and results described in this paper should be viewed as a feasibility study. It is

difficult, if not impractical, to have darkrooms set up in a plant specifically for fit testing. Improvements to this method and subsequent validation are needed if a practical fit test for general industry is to evolve. Hopefully, this study shows that there are inexpensive fit tests which can be developed that do not rely on a sensory response from the user.

Acknowledgment

I wish to thank Tom Kavlick and Joseph Wolfsberger of the Monsanto Company for their assistance in running the QNFT tests. I also want to thank Ken Farquarson, Olin's photographer, for sharing his darkroom and ideas with me. Finally, it would have been impossible to develop a new fit test without the support of the employees who volunteered for these tests.

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