

WHERE ARE WE IN RESPIRATOR QUANTITATIVE FIT TESTING

-A CRITIQUE OF QFT SYSTEMS AND THEIR USES-

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## INTRODUCTION

To answer the question "Where are we in respirator quantitative fit testing (QFT)" that the program committee invited me to discuss, I believe it is necessary to consider several items including 1) the various types of QFT systems developed in the last 20 years, 2) some of the QFT systems uses and abuses by government agencies, manufacturers and employers and 3) the Los Alamos Scientific Laboratory (LASL) QFT results on anthropometric test panels that are available. Sufficient data exists to justify the use of QFT systems with anthropometric panels for approval at specified levels of production. Areas where there is insufficient data will be discussed along with a review of research needs on the subject.

I will review the old LASL QFT data with male test subjects only and methods used to determine the PFs currently used by OSHA and NIOSH. Additional QFT data will all types of devices on anthropometric panels (male and female) now available will be presented.

A proposed OSHA regulation requiring QFT on wearers before a standard QFT method is adopted and before a minimal acceptable respirator program is in use to assure that respirators are properly selected, used, and maintained is discussed. The efforts of LASL, OSHA, ASTM and others to establish a standard for QFT systems use are discussed.

## DEVELOPMENT OF QFT SYSTEMS

The types of QFT systems developed since 1960 include laboratory and field test systems. The laboratory systems are used primarily to measure facepiece leakage on air-purifying respirators and overall leakage on atmosphere-supplying devices. Laboratory QFT systems used for approval testing should include a test panel representative of female and male workers. The field test systems measure the overall leakage of specific contaminants that respirator wearers are exposed to during their normal work in industry.

### A. Laboratory Systems

#### 1. Aerosol Systems

In the U.S. Burgess<sup>1</sup> and Silverman developed a uranine aerosol system in 1961 and noted at the time that the U.S. Bureau of Mines (BofM) was experimenting with a DOP aerosol system for QFT. The BofM DOP aerosol system was described and illustrated in the Respirator Manual by Pearce<sup>2</sup> in 1963. In 1965, BofM Schedule 21B<sup>3</sup> was put into effect with both DOP and uranine aerosol QFT systems used to test and approve respirators with high efficiency filters.

In 1963, Hounam<sup>4</sup> developed a sodium chloride aerosol QFT system which has been used routinely at the Harwell AERE in the UK. In 1966 White<sup>5</sup> described the sodium chloride aerosol system developed and used routinely at the Canadian Chalk River AERE. Dorman<sup>6</sup> reported the development of a sodium chloride aerosol QFT system developed at the UK Civil Defense

Establishment that was the QFT system adopted in BS-4400-1969<sup>7</sup>. In 1970 Burgess<sup>8</sup> described the development of a sodium chloride aerosol QFT system. In 1971 Persson<sup>9</sup> in Sweden reported the development and use of a DOP aerosol QFT system used to test SCBA.

In 1970 LASL developed a thermally generated mono-dispersed DOP aerosol QFT system<sup>10,11</sup> to duplicate the BofM system. In 1971 an air-generated poly dispersed DOP aerosol QFT system<sup>12</sup> was developed, tested, and two units were delivered to the NIOSH in 1973. In 1972, the LASL sodium chloride aerosol QFT system<sup>13,14</sup> was developed, tested and two units were delivered to the NIOSH in 1973. The NIOSH Testing and Certification Branch (TCB) planned to use the two types of QFT systems developed by LASL for testing and certification purposes. This would require many additional QFT systems that would be used by respirator manufacturers and others. In an effort to encourage the commercial development of a standardized QFT system, LASL prepared and submitted purchase specifications based on the DOP and sodium chloride aerosol QFT systems developed and delivered to the NIOSH. Two manufacturers did develop and deliver prototype poly DOP and sodium chloride aerosol QFT systems that were evaluated and accepted. These two companies, ATI and Frontier, have since developed and manufactured many improved models of the two QFT systems.

In 1976, LASL developed a QFT system<sup>15</sup> to evaluate atmosphere-supplying devices and powered air-purifying respirators which dilute challenge agents by exhausting air during operation at flow rates ranging from 4 to 16 cfm (115 to 460 L/min).

The large 16 m<sup>3</sup> test chamber is capable of delivering 75 ft.<sup>3</sup>/min (2.12 m<sup>3</sup>/min) poly-dispersed DOP aerosol at a concentration of 25 mg/m<sup>3</sup>. A forward-scattered light photometer is used to measure aerosol concentration. The photometer sensitivity is sufficient to measure penetration less than 0.01%. Turbulent mixing of the aerosol results in a uniform aerosol concentration at various points in the chamber that varied less than 1% of the concentration in the center of the chamber. Figure 1 is a schematic diagram of the test chamber.

## 2. Gas Systems

The Freon-12 gas QFT system developed and used to evaluate self-contained breathing apparatus (SCBA) at the Hanford AEC Project was described by Adley<sup>16</sup> in 1962. In the UK, Morgan<sup>17</sup> reported the development of a Freon-12 QFT system.

A Freon-12 gas QFT system was developed at the BofM and reported by Gussey<sup>18</sup> in 1971. In 1975, Packard<sup>19</sup> described the Freon-12 gas QFT system developed by the DOW Chemical Company to test and train workers in the use of mouthpiece respirators used for protection against chlorine.

In 1971, Griffin<sup>20</sup> described the development of an argon gas QFT system used to test SCBA at the UK Mine Research Establishment.

A sulfur hexafluoride gas QFT system<sup>21</sup> was developed and tested at LASL and reported in 1978. In Japan, Inouye<sup>22</sup> described a sulfur hexafluoride gas QFT system he had developed and used to evaluate the overall performance of SCBA in 1979. In West Germany, Pasternack<sup>23</sup> described an ethylene gas QFT system developed and commercially available from the Drager Company in 1978.

### 3. Representative Test Panel

An anthropometrically selected test panel representing a mix of approximately 95% of male and female workers in the U.S. was developed for NIOSH by LASL<sup>24,25</sup> and McConville<sup>26,27</sup>. For this 25-person QFT panel used for testing half-mask respirators, subjects were selected based on nose length and lip length. The full facepiece panel selection is based on nose length and face width as shown in Figure 2. These test panels have been used by LASL since 1974 for QFT studies on all types of devices. Other investigators, including respirator manufacturers, have selected and used 25-person panels during the last five years.

### B. Field Test Systems

QFT systems worn by workers doing normal or regular work are very cumbersome and often technically complex. Burgess<sup>28</sup> developed a QFT system to test the overall leakage of respirable size coal dust and dust respirators worn by coal miners doing normal underground shift work\*. A QFT system to test both the overall leakage of solvent and particulates of respirators worn during spray painting was developed and used by Toney<sup>29</sup>.

Austin<sup>30</sup> and Moore<sup>31</sup> have described QFT systems used for field testing devices worn for respiratory protection during abrasive blasting and sulfur dioxide exposures in smelters.

## STANDARD QFT SYSTEMS - STATUS

The need for standardized QFT systems for use by government and industry has been recognized in the U.S. for many years. To assure uniform protection throughout the world where imported respirators are used, an international standard for QFT systems is needed. The following summarizes the status of some efforts in the U.S. to develop such a standard.

### A. LASL QFT Work Shop

A QFT work shop was held at LASL in March 1977. The work shop was sponsored by the LASL Respirator R & D Section at the request of OSHA. The Chairman of the work shop was D. Douglas. The two-day agenda including reports by 20 users of QFT systems and a round table discussion to outline a proposed standard for respirator QFT systems. The major points of the proposed standard agreed upon by a majority of the participants was as follows:

#### 1. Test Agents;

The minimum sensitivity for sodium chloride and poly/DOP aerosol test agents and freon-12 gas test agent was 0.02%. The concentration range for the sodium chloride aerosol was 10-20 mg per cm with an aerosol size ranging from

0.5 to 0.7 micrometers. The concentration of the poly/DOP aerosol would range from 20-40 mg per cm with a size of 0.5 to 0.7 micrometers. The concentration range of the freon-12 gas test agent would range from 250 to 1000 ppm.

## 2. Test Chamber:

The proposed standard specified that the test chamber have a constant concentration  $\pm 5\%$  of the selected concentration. Also, the test agent would be uniformly distributed in the test chamber, it would be of an adequate size for specified exercises and there would be visible contact with the subject at all times.

## 3. Other Criteria:

The seven exercises proposed included a smile for half-mask and a frown for a full facepiece. The data collected would be by a recorder and the operator would write any calculations or estimates on the recorder chart.

## B. NIOSH Activities

A meeting of representatives from respirator manufacturers, OSHA, NIOSH, and others was called by NIOSH/TCB in Washington, DC on June 14, 1978, to discuss what QFT systems should be added to the 30 CFR 11 approval schedules. One of the major concerns at this meeting was the variability of QFT results with the same respirator on the same person. A major concern among participants was the number of persons that would be used on a QFT panel for testing and certification. The number of persons proposed ranged from a minimum of 10 which NIOSH-TCB said was feasible from a procurement viewpoint to a high of 50-60 from a statistical viewpoint.

An inter-agency QFT seminar was held by NIOSH in Cincinnati, Ohio, September 19, 1978, for NIOSH and OSHA personnel with three consultants to discuss a proposed QFT system with test panel for revision of 30 CFR 11.

## C. OSHA

During the past three years, OSHA Health and Safety personnel have prepared drafts of a proposed standard QFT system. OSHA recognizes that they must adopt a QFT standard of their own or adopt one prepared by a consensus standard organization when requiring the use of a QFT system in their standards.

## D. ASTM E-34.14 Respirator Task Force

For the past two years, the ASTM E-34.14 Respirators Task Force has been working on a proposed QFT standard. This activity has been assigned to Work Group II under the chairmanship of Truman Williams. The minutes of their June 19-20, 1971, meeting indicated that one of the questions was whether or not aerosol challenge test agents would give fit factors comparable to QFT runs with gas challenge agents. Lowry<sup>15</sup> showed that gas and sub-micron aerosol test results were comparable in LASL experiments with SF<sub>6</sub> and poly

DOP. Dudley of Scott Aviation has found that fit factors obtained using helium are equivalent to the factors obtained using sodium chloride or DOP and that aerosols act like gases. In the UK, Dorman<sup>0</sup> has shown that results of QFT on SCBA with argon gas and sodium chloride aerosol are comparable.

#### QFT SYSTEMS USE FOR APPROVAL

##### A. Status Use of Approval in U.S.A.

In 1965, the BofM in their approval Schedule 21B<sup>3</sup> adopted uranine and DOP aerosol QFT systems for approval testing of particulate respirators for protection against highly toxic airborne particulates such as plutonium or beryllium. During the period 1965 to 1972, the BofM used the DOP aerosol only in their QFT to measure the facepiece leakage of particulate respirators worn by six men with widely varying facial sizes and shapes to determine if they met the leakage criteria for protection in aerosol concentration up to 10, 100, or 1000 times the TLV or MPC. Although the BofM did not specify the type of facepiece for these various levels of respiratory protection, in practice they approved seven half-mask respirators for a protection level of 10 X TLV (PF=10) and seven full facepiece masks for protection level of 100 X TLV (PF = 100).

The first draft of 30 CFR Part 11, published in March 1971, proposed that PFs for certain types of respirators would be determined based on QFT systems using a DOP aerosol. Following official hearings on this proposal, and adverse comments relative to PFs, the NIOSH/BofM sponsored 30 CFR 11,<sup>32</sup> published March 25, 1972, deleted QFT and PFs with the following statement in the introduction of Part 11 "the Bureau and the Institute have decided that although the concept of PFs is valid, present technology in this area is insufficient to produce reliable data upon which to base such factors." They did indicate that they would work to improve relevant technology (QFT) and data in order to incorporate requirements for PFs into Part 11 at a later date. Since 1972, the NIOSH has periodically activated work on amendments to Part 11 to incorporate QFT on representative test panels based on research and development that they have sponsored.

##### B. Use of QFT and BS 4400-1969

A sodium chloride aerosol QFT test system to measure facepiece leakage on dust respirators worn by 10 test subjects is described in BS 4400:1969. In this standard, the maximum leakage permitted varies depending upon the type and class of respirators tested. Based on the criteria specified in this and other British standards, Barraclough<sup>33</sup> published a table of PFs for various types of respirators that met the minimum criteria specified in British Standards.

#### PROTECTION FACTORS: BASIS AND QFT DATA USED

##### A. Background in U.S.A.

The first official definition of the term protection factor was made by the BofM in Schedule 21B<sup>3</sup> published in 1965. Although the BofM did not use the term protection factor on their approval labels, they did approve particulate

removing respirators for protection against highly toxic particulates with a maximum use concentration. Half-mask respirators equipped with a high efficiency filter were approved for use up to 10 X the TLV (PF=10). Also, full facepiece respirators equipped with a high efficiency filter were approved for protection up to 100 X TLV (PF=100).

#### B. Nuclear Regulatory Commission (formerly AEC Director of Regulation)

In 1967, the AEC<sup>34</sup> Director of Regulations published proposed PFs in the Federal Register that range from 10 for high efficiency particulate removing half-mask respirators to 10,000 for positive pressure SCBA. Due to adverse criticism relative to the lack of adequate QFT results on all types of devices, the proposed PF table was withdrawn. To substantiate or determine universally accepted PFs for all types of devices, the AEC Director of Regulation sponsored a Respirator Study Program at the LASL starting in July 1969. This NRC Project has been sponsored at LASL with J. Caplin as Project Coordinator for the past 11 years. Based on these studies, LASL has conducted DOP aerosol QFT leakage and/or performance test and reported PFs for: 1) half and full facepiece respirators equipped with high efficiency filters,<sup>10,11,14,21</sup> 2) self-contained SCBA breathing apparatus operated in both the demand (NP) and the pressure-demand (PP) modes,<sup>7,38</sup> 3) supplied-air hoods,<sup>1</sup> and 4) supplied-air respirators. Type C, operated in continuous flow, demand, or pressure demand modes.<sup>9,40</sup>

#### C. Use of LASL QFT Data to Assign Protection Factors

##### 1. Basis of PFs Now Used by OSHA and NIOSH

The PFs published in the Respirator Decision Logic by the Respirator Committee of the Joint NIOSH/OSHA Standards Completion Program (SCP) are based on LASL QFT results. The NIOSH sponsored a project at LASL which resulted in the publication of a report titled "Respirator Protection Factors". This report by Hyatt<sup>35</sup> was reviewed and approved by the SCP Respirator Committee before being submitted as legal evidence in the OSHA Ketone hearings conducted in September 1975. LASL QFT data used was collected on male test subjects only during period 1971 to 1973 with BofM approved respirators. The PFs in this report were intended only as interim PFs until 1) 30 CFR Part 11 was amended to require QFT on representative test panels as a basis for PFs or 2) QFT results on a representative male and female panel was available on the various types of devices.

Since 1973, many QFT results on representative test panels have been reported by LASL on all types of devices. The author has pointed out to both the Director of NIOSH and Assistant Labor Secretary for OSHA that this new data is available and it should be used to revise the PFs used in the Respirator Decision Logic and adopted by OSHA in all of their published standards for various contaminants and in their 1979 Field Operations Manual. All of the following QFT results were obtained on representative male and female test panels and were submitted to OSHA and NIOSH in 1978 by the author with the strong recommendations that PFs used by OSHA should be revised based on this new data.

## 2. LASL QFT Data on Quarter and Half-Mask Dust Respirators

The results of QFT on 20 different NIOSH/MSHA approved quarter and half-mask dust respirators and 3 sizes of Draeger half-mask dust respirators in Table 1 were performed at LASL under NIOSH sponsorship during the period 1974 through September 1978.

The TDA-60 sodium chloride aerosol QFT system used to obtain the results in Table 1 was a commercial version of LASL designed units sent to the NIOSH. In an effort to eliminate variations in fitting between QFT results on one person wearing one type respirator, each person was carefully fit. To avoid fluctuations in the seal due to extreme differences in strap tension, a Check-Line Tension-Meter was used to adjust strap tension within a range of 340 to 450 g. tension for all quarter and half-mask facepieces tested. The development and calibration of the tension measurement is reported by Held<sup>36</sup>. The best possible fit was obtained (all prescription eye glasses removed) with one respirator on all size faces, even if the nose cup came up to the eyebrows and/or chin cup extended to the adam's apple. The major purpose of the study was to verify the test panel proposed with many types of dust respirators.

The details of the study including selection of panel, equipment and test procedures used, results of QFT on six half-masks (Numbers 1, 5, 19, 21, 22 and 23 in Table I) are described by Douglas<sup>12</sup> for the first year of the four-year study. I believe the following conclusions in the LASL report are generally valid today.

- a. The data presented tends to support the conclusion that a respirator facepiece will give consistent fit test results when tested on the faces that it is clearly designed to fit. Inconsistence itself is an indication of poor fit and should be cause for non-approval of a respirator.
- b. The six half-masks tested during the first year of the study offer reasonable protection for men. The worst performing respirator, Number 19 in Table I, protects 10 times as many men as women while the best fitting respirator, Number 5, protects all the men represented on the panel (FP=10) and 83% of the women.
- c. The better performing half-masks appear to be smaller and, especially narrower, than the poorer performers. It appears to be a fact of mask design that narrower half-masks can deform to accommodate wide faces but the converse is not true, i.e., wide masks cannot be adjusted to seal on narrower faces.
- d. Four-point strap suspension again appears superior to two-point, which confirms the recommendations that LASL made to the AEC in 1971.
- e. Anthropometric test panels for determining the face fit of respirators can be established by screening a reasonable number of people. For the LASL panel, screening less than 150 people provided sufficient subjects of the required sizes to supply more than two panels for both full facepiece and half-mask respirators.

This data illustrates the wide differences in the fitting quality of the many types of dust respirators tested on a representative male and female test panel. The results indicate that a PF of 10 cannot be safely assigned to all of the dust respirators listed in Table I. If the NIOSH and OSHA still believe that it is necessary to assign a PF to one class of respirator based on the poorest fitting one, then it is suggested that a maximum PF of 5 be assigned to both quarter and half-mask dust respirators.

### 3. LASL QFT Results on Full Facepiece Dust Respirators

The results of LASL QFT on representative male and female test panels for NIOSH/MSHA approved full facepiece respirators equipped with high efficiency filters is shown in Table II. The results show that all but one of the full facepiece respirators could be safely assigned a PF of 100 based on the suggested criteria that 90% of the panel must obtain an average facepiece leakage less than 1.0%.

The full facepieces were carefully fitted on all test subjects in this NIOSH study as described in Section 2 above for half-masks, except strap tension was not measured due to shape of headbands.

4. Table III compares QFT results obtained on a 31-male fireman panel testing SCBA in a 1971-72 NRC Study<sup>37</sup> with results on a 25-person male and female panel testing SCBA in a 1978 NRC Study reported by Hack<sup>38</sup>. The first study was performed using thermally generated mono dispersed DOP in a small 4 X 4 chamber while the 1978 study was made in the large 14 X 6' new poly dispersed DOP chamber previously described. All of the test were made on SCBA operated in the demand mode (negative pressure).

Both studies also tested SCBA operated in the pressure demand mode (positive pressure). In the 1971-72 study, all 31 firemen had leakages less than 0.01% when testing SCBA in the pressure demand mode. In the 1978 study, all of the 10 person panel achieved a leakage of less than 0.01% while testing only four of the six types of SCBA operated in the pressure demand mode.

### 5. LASL QFT Results on Supplied-Air Respirators

The results of an extensive NRC Study on supplied-air respirators has been reported by Hack<sup>39,40</sup>. During the study, a total of 10 continuous flow type respirators, equipped with either half-mask or full facepiece, were evaluated along with seven pressure demand type respirators with either half-mask or full facepiece. In addition, eight demand-type supplied-air respirators were tested.

Hack concludes that the data supports a protection factor of 5,000 for all pressure demand types while eight of the ten respirators that provide only continuous flow achieved PFs of 5,000 or better at the minimum air pressure recommended, and all of them achieved a PF of 5,000 or better at the maximum flows recommended. The major recommendation in this report was that demand type supplied-air respirators should never be used or approved. (See Table IV)

## 6. LASL QFT Results on Hoods

In 1976, Douglas<sup>41</sup> reported an NRC Study designed to evaluate the performance of supplied-air hoods using the LASL large chamber poly DOP aerosol QFT system. The results of this study indicate that the 6-8 test subjects wearing approved abrasive blasting hoods could achieve a PF of 10,000 or higher during most exercises performed by the subjects during the QFT, the running in place proved to be the most severe relative to producing leaks due to the fact that the hood did not stay in place on the wearer's head.

Douglas notes that the recommendation of PFs is influenced by the importance of maintaining a minimum air flow of 170-Lpm (6 cfm). He recommends a PF of 1,000 for approved hoods if a calibrated airline pressure gage or flow measuring equipment is used to maintain the minimum pressure recommended. Also, he recommends that a PF of 2,000 can be used at maximum air flows recommended by the manufacturers.

## 7. LASL QFT Results on PAPR

In 1977, Lowry<sup>15</sup> reported the results of QFT on five types of PAPR equipped with high efficiency filters, including one unit manufactured in the UK. The results of this NRC Study showed that when the minimum recommended air flow is maintained a PF of 10,000+ can be achieved with tight-fitting facepieces. This same PF can be achieved on the U.S. approved PAPR equipped with a hood.

### CURRENT USE OF QFT BY EMPLOYERS

The use of a QFT system to evaluate the fit of the respirator facepiece to the ultimate wearer provides an accurate and meaningful measurement of facepiece leakage for each person and respirator combination. Some employers in the U.S. started QFT on all respirator users when QFT systems became commercially available in 1973.

#### A. QFT Use by Employers Choice

In the U.S. and UK the first employers to use QFT systems were Atomic Laboratories or projects. In the UK, sodium chloride aerosol QFT systems are commercially available and have been used for many years by Atomic Energy establishments and others. Similar QFT systems have been routinely used at the Canadian Chalk River establishment.

In the U.S., many of the DoE (formerly AEC) contractors and NRC Nuclear Power Plants have routinely used QFT systems for several years. The employees perform a QFT on the types of air-purifying respirators to be used and must meet specified fit criteria chosen by the employer. Leigh<sup>42</sup> has reported the routine use of QFT systems and his studies with an anthropometric test panel.

In the chemical industry, Packard<sup>19</sup> has reported the development, fabrication and routine use of Freon-12 gas QFT systems to fit and train workers with mouthpiece respirators used for protection against chlorine in at least 10 different plants.

## B. QFT Use by Regulation

The current OSHA standards for arsenic and lead require the use of QFT for employees wearing air-purifying respirators for protection against these contaminants. This regulation applies to all plants regardless of the number of workers exposed to arsenic or lead.

The required use of QFT in the OSHA Lead Standard has been challenged as 1) not necessary because a qualitative fit is adequate to assure proper respiratory protection when used where a minimal acceptable respirator program exists, 2) unenforceable and impractical without an OSHA QFT standard, 3) not economically feasible for small plants with 2-20 workers exposed to lead and 4) a QFT does not assure satisfactory respiratory protection when the respirator is not properly used and maintained.

It is important to emphasize that the original OSHA regulation (1910.134) on the use of respirators required the employer to adopt and enforce a minimal acceptable respirator program. Apparently, due to the lack of training and the difficulties in enforcing a minimal acceptable respirator program, many respirator users are observed in industry where the respirator is being improperly worn or used and poorly maintained respirators are being worn. It is obvious that requiring a QFT on each respirator wearer when it is improperly worn will not assure adequate respiratory protection.

When the OSHA standard permits the employer to use a maximum PF of 10 for half-masks and 50 for full face masks, there is no incentive for the employer to do QFT on all of his employees.

At present, several large companies operating smelters with arsenic exposures are performing QFT on air-purifying respirator users. Some of the large companies such as General Motors with many workers exposed to lead have purchased QFT systems and are either performing QFT tests or training personnel to do so.

It is worth noting the experience of an Australian smelter in 1965 that could only achieve good respiratory protection when a qualitative fit was made on all employees and the properly fitted respirators were worn. Before a qualitative fit was initiated in the smelter on all employees, Thomson<sup>43</sup> reported that approximately 20% of the workmen had high blood-lead levels.

## C. QFT and PFs Proposed in ANSI Z88.2-1980

The ANSI Z88.2-1980 Standard for respirator use lists a table of protection factors according to whether qualitative or quantitative fitting is performed. This standard allows higher PFs to be used when they are obtained using a good QFT system.

The respirator PF permitted according to the fitting method used permits an increase from 10 for qualitative fit to a maximum of 100 for quantitative fit for quarter or half-mask facepiece particulate filter respirators and from, 100 to a maximum of 1,000 for full facepiece respirators equipped with high efficiency filters. This is a realistic standard that permits a safe incentive to the employer for the use of QFT systems.

## RESPIRATOR DEFECTS AND USE PROBLEMS REVEALED BY QFT

During the first two years, QFT was used by the Respirator R & D Section at LASL, several respirator defects and/or use problems were revealed during QFT on volunteer male test subjects.

### A. Negative Pressure Air-Purifying Respirators

In several cases, leaks were found to originate in the exhalation valve of quarter masks, half-masks, and full facepiece masks. Significant leakage occurred due to lint and/or dirt found on valve seat of both new and used respirators purchased in the U.S. and abroad. LASL found that on one European full facepiece small amount of factory dust caused a leakage of 0.05 to 0.1%. In another example, a U.S. full facepiece exhalation valve was leaking approximately 5% because the valve had been improperly assembled in the factory and was sitting approximately 1/4" off the valve seat. LASL found that the most popular quarter mask dust respirator sold in the U.S. could give leakages up to 50% due to the exhalation valve sticking in the valve seat and creating a permanent opening. The respirator manufacturers immediately corrected such problems.

Other use problems or defects revealed were leakage due to a poor gasket and filter seal. Another leakage was due to the slippage of full facepiece head bands when turning head, which was caused by worn serrations on the silicone head bands.

### B. Positive Pressure Atmosphere-Supplying Devices

QFT has shown leakages on all types of positive pressure atmosphere-supplying devices due to the lack of a positive pressure at all times inside the facepiece.

During our first QFT on SCBA in 1971, LASL found some leakage on units operated in the pressure demand mode due to the fact that the positive pressure was only 0.3 to .4 inches W.G. This was observed on used and a new SCBA that had never been used.

Continuous flow supplied-air hoods were evaluated and significant levels of leakage were observed in one brand due to defect (hole) in the approved hood. During QFT on all types of approved supplied-air respirators, equipped with tight-fitting facepieces, excessive leakage was found on very large, poor-fitting facepieces in spite of maintaining the minimum required flow of 4 cfm.

### C. Quality Control of Facepieces on Head Form with QFT Unit

Many respirator manufacturers are using a QFT unit to perform quality control on all new facepieces mounted on a standard head form. Extensive quality control testing carried out during the past 7 years at the Rocky Flats, Colorado Nuclear Plant has revealed a significant number of new half-mask and full facepiece masks that permit some detectable leakage. The Rocky Flats plant routinely runs quantitative leak tests on all facepieces after maintenance.

This system wherein the stream of DOP aerosol of unknown concentration is run around the periphery of the facepiece mounted on the head form reveals leakages of unknown quantity. This type of test should be used by every respirator manufacturer and standard quality control methods should be adopted and used.

#### CONCLUSIONS AND RECOMMENDATIONS

A. Sufficient data exists to justify the use of QFT systems with an anthropometric test panel to measure facepiece leakage for approval of respirators to meet specified criteria for meaningful PFs. The proposed LASL full facepiece panel should be used to test all types of facepieces.

B. LASL QFT results on all types of NIOSH-approved devices and other published QFT data should be used as the basis and justification to revise current OSHA PFs until QFT systems are in use for approval. Until this is done, OSHA should adopt the respirator PFs proposed in the new ANSI Z88.2-1980 Respirator Use Standard and permit the proposed higher PFs when QFT is used.

C. The required use of QFT systems in some OSHA health standards is not justified without adoption of a standard QFT system. Also, it will not assure adequate respiratory protection if the respirator is not properly worn and maintained. OSHA should give top priority to the preparation and adoption of a QFT system standard and enforce the proper use and maintenance of respirators.

D. The use of the QFT systems commercially available by trained operators to evaluate the fit of the respirator facepiece to the ultimate wearer, provides an accurate and meaningful measurement of facepiece leakage for each person and respirator combination where a minimum respirator program is enforced. Minimum qualifications and training for QFT systems operators should be established.

E. Some LASL QFT data from NIOSH studies tends to support the conclusion that a respirator facepiece will give consistent test results when tested on the faces that it is clearly designed to fit. Unpublished reproducibility QFT results by several investigators show wide variations. Variations in QFT results on one person on one properly sized respirator is commonly due to variations in strap tension and improper wearing by poorly trained and/or poorly motivated wearers.

F. Insufficient data exists to:

1. prohibit use of qualitative fitting tests
2. verify level of protection provided to wearer during actual use
3. resolve differences reported on QFT reproducibility tests
4. verify high PFs used for positive pressure SCBA during high work rates
5. standardize multiple facepiece sizes for National or International adoption.
6. verify that there is no difference in QFT results with aerosol and gas test agents.

G. Top priority should be given to resolve the question of toxicity of QFT test agents.

## REFERENCES

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TABLE 1

RESULTS OF **LASL** <sup>(1)</sup> QUANTITATIVE FIT TESTS <sup>(2)</sup> WITH QUARTER  
AND HALF-MASK FACEPIECES <sup>(3)</sup> EQUIPPED WITH HIGH EFFICIENCY  
FILTERS ON REPRESENTATIVE TEST PANEL <sup>(4)</sup>

| t   | <u>Respirator Tested</u> | Persons<br>on<br><u>Panel</u> | <u>Type</u> | Percent Panel with <b>Leakage</b> <sup>(5)</sup><br>Less Than |             |             |
|-----|--------------------------|-------------------------------|-------------|---------------------------------------------------------------|-------------|-------------|
|     |                          |                               |             | <u>10.0%</u>                                                  | <u>2.0%</u> | <u>1.0%</u> |
| 1.  | MSA Comfo <b>II-M</b>    | 35                            | 1/2         | 91                                                            | 80          | 69          |
| 2.  | MSA Comfo II-M           | 25                            | 1/2         | 100                                                           | 100         | 100         |
| 3.  | MSA Comfo <b>II-S</b>    | 25                            | 1/2         | 84                                                            | 72          | 64          |
| 4.  | MSA Dustfoe 88           | 35                            | 1/4         | 100                                                           | 91          | 86          |
| 5.  | Willson 1212             | 35                            | 1/2         | 97                                                            | 83          | 74          |
| 6.  | Willson 500              | 35                            | 1/4         | 80                                                            | 57          | 40          |
| 7.  | <b>AOR-6057</b>          | 35                            | 1/2         | 37                                                            | 20          | 20          |
| 8.  | <b>AO R-5057</b>         | 35                            | 1/2         | 80                                                            | 74          | 74          |
| 9.  | AOR-2000                 | 35                            | 1/4         | 86                                                            | 69          | 60          |
| 10. | <b>Glendale-2000</b>     | 35                            | 1/2         | 40                                                            | 23          | 23          |
| 11. | <b>Glendale-4000</b>     | 35                            | 1/4         | 91                                                            | 83          | 80          |
| 12. | <b>Pulmosan C-263</b>    | 35                            | 1/2         | 71                                                            | 46          | 20          |
| 13. | <b>Pulmosan C-264</b>    | 35                            | 1/4         | 83                                                            | 29          | 14          |
| 14. | Cesco 94                 | 35                            | 1/2         | 89                                                            | 80          | 71          |
| 15. | Cover-No Chin Cup        | 35                            | 1/2         | 91                                                            | 71          | 71          |
| 16. | <b>Cover-No</b> Chin Cup | 25                            | 1/2         | 100                                                           | 72          | 64          |
| 17. | <b>Scott-L</b>           | 25                            | 1/2         | 93                                                            | 86          | 86          |
| 18. | <b>Scott-S</b>           | 25                            | 1/2         | 93                                                            | 71          | 68          |
| 19. | Norton 7580-L            | 25                            | 1/2         | 84                                                            | 68          | 60          |
| 20. | Norton <b>7580-M</b>     | 25                            | 1/2         | 96                                                            | 92          | 88          |
| 21. | Draeger <b>R27-201-L</b> | 35                            | 1/2         | 43                                                            | 31          | 31          |
| 22. | Draeger <b>R27-202-M</b> | 35                            | 1/2         | 86                                                            | 74          | 74          |
| 23. | Draeger R27-203-S        | 35                            | 1/2         | 89                                                            | 74          | 57          |

FOOTNOTES FOR TABLE 1:

(1) The Respirator R & D Section in the Industrial Hygiene Group of the Los Alamos Scientific Laboratory (LASL) conducted this project with NIOSH-TCB sponsorship.

(2) The Method of Fitting the facepiece on each subject was controlled by the operator. Example: each subject adjusted headbands until the same tension was obtained on all facepiece headbands as measured by the operator.

(3) To primarily measure facepiece leakage only, each approved dust, fume, and mist respirator was equipped with high efficiency filters (99.97% + efficient against 0.3 micron DOP).

(4) The test panel is representative of 95% of U.S. male and female workers and is discussed in text.

(5) The leakage listed is the average sodium chloride aerosol penetration calculated from recorded penetrations during each of six exercises performed by each subject during test.

TABLE II

RESULTS OF LASL QUANTITATIVE FIT TESTS WITH FULL FACEPIECE  
RESPIRATORS<sup>(1)</sup> EQUIPPED WITH HIGH EFFICIENCY FILTERS  
ON REPRESENTATIVE 35 PERSON TEST PANEL

| <u>Full Face Mask</u> | Percent Panel w/Leakage <sup>(2)</sup> Less Than |             |             |
|-----------------------|--------------------------------------------------|-------------|-------------|
|                       | <u>1.0%</u>                                      | <u>0.2%</u> | <u>0.1%</u> |
| MSA-UltraVue          | 100                                              | 100         | 97          |
| Scott 742             | 97                                               | 91          | 86          |
| Willson 1700          | 97                                               | 77          | 71          |
| Scott/Acme 805        | 91                                               | 77          | 66          |
| Norton/Welsh 7680     | 83                                               | 69          | 51          |

FOOTNOTES:

(1) Full facepiece respirators approved by NIOSH/MSHA with high efficiency filter and approved for highly toxic aerosols.

(2) The leakage listed is the average sodium chloride aerosol penetration calculated from recorded penetration during each of six exercises performed by each subject during test.

TABLE III  
FREQUENCY DISTRIBUTION OF FACEPIECE LEAKAGE OBTAINED BY SUBJECTS  
TESTING SCBA.\* COMPARISON OF 31 FIREMEN PANEL VS 25 PERSON MALE  
AND FEMALE PANEL

| Manufacturer and<br>Type Full Facepiece | Year<br>Tested | No.<br>Subj. | Percent of Subject with Leakage<br>Less Than % Listed |             |            |            |            |            |
|-----------------------------------------|----------------|--------------|-------------------------------------------------------|-------------|------------|------------|------------|------------|
|                                         |                |              | <u>0.01</u>                                           | <u>0.05</u> | <u>0.1</u> | <u>0.2</u> | <u>1.0</u> | <u>2.0</u> |
| 1. MSA                                  |                |              |                                                       |             |            |            |            |            |
| a. Clearvue                             | 71-72          | 31           | 52                                                    | 74          | 87         | 97         | 97         | 100        |
| b. Ultravue                             | 71-72          | 31           | 74                                                    | 77          | 84         | 97         | 97         | 100        |
| c. Ultravue                             | 78             | 25           | 4                                                     | 12          | 32         | 44         | 80         | 92         |
| 2. Scott                                |                |              |                                                       |             |            |            |            |            |
| a. Old Scottoramic                      | 71-72          | 31           | 13                                                    | 48          | 58         | 68         | 90         | 100        |
| b. New "                                | 71-72          | 31           | 10                                                    | 23          | 48         | 74         | 84         | 100        |
| c. New " 742                            | 78             | 25           | 4                                                     | 4           | 24         | 40         | 96         | 96         |
| d. 4.5 Plastic                          | 78             | 25           | 0                                                     | 12          | 28         | 28         | 60         | 64         |
| 3. Globe                                |                |              |                                                       |             |            |            |            |            |
| a. Sierra-N                             | 71-72          | 31           | 26                                                    | 65          | 81         | 97         | 100        |            |
| b. Sierra                               | 78             | 25           | 0                                                     | 0           | 8          | 12         | 48         | 55         |
| 4. Survivair                            |                |              |                                                       |             |            |            |            |            |
| a. D/PD-Silicone                        | 71-72          | 31           | 58                                                    | 77          | 88         | 94         | 97         | 97         |
| b. D/PD-Neoprene                        | 71-72          | 31           | 0                                                     | 19          | 39         | 71         | 87         | 94         |
| c. D/PD                                 | 78             | 25           | 4                                                     | 4           | 16         | 28         | 68         | 72         |
| d. D Only                               | 78             | 25           | 0                                                     | 4           | 12         | 24         | 76         | 84         |

\*SCBA in Demand Mode (Negative Pressure)

TABLE IV  
FREQUENCY DISTRIBUTION OF PERCENT FACEPIECE LEAKAGE OBTAINED BY PANEL  
DURING 77-78 LASL TESTS ON SAME FULL FACEPIECE USED WITH 1) AIR-PURIFYING  
(A-P), 2) SUPPLIED-AIR (S-A) IN DEMAND MODE, AND 3) SCBA IN DEMAND MODE

| Manufacturer and<br>Type of<br>Full Facepiece | No.<br>Sub-<br>jects | Aero-<br>sol | Accumulative % of Subjects with Face-<br>piece Leakage Less Than % Listed |             |            |            |            |            |            |
|-----------------------------------------------|----------------------|--------------|---------------------------------------------------------------------------|-------------|------------|------------|------------|------------|------------|
|                                               |                      |              | <u>0.02</u>                                                               | <u>0.05</u> | <u>0.1</u> | <u>0.2</u> | <u>0.5</u> | <u>1.0</u> | <u>2.0</u> |
| 1. MSA                                        |                      |              |                                                                           |             |            |            |            |            |            |
| a. A-P, UV, Twin                              | 35                   | NaCl         | 46                                                                        | 86          | 97         | 100        | 100        | 100        | 100        |
| b. S-A, UV,                                   | 25                   | DOP          | 4                                                                         | 16          | 20         | 44         | 72         | 88         | 96         |
| c. SCBA, UV                                   | 25                   | DOP          | 12                                                                        | 20          | 32         | 44         | 68         | 80         | 92         |
| 2. Scott                                      |                      |              |                                                                           |             |            |            |            |            |            |
| a. A-P, 742                                   | 35                   | NaCl         | 57                                                                        | 83          | 86         | 91         | 91         | 97         | 100        |
| b. S-A, 742 Std.                              | 25                   | DOP          | 8                                                                         | 8           | 20         | 20         | 28         | 68         | 92         |
| c. S-A, 742 Tite                              | 25                   | DOP          | 0                                                                         | 12          | 20         | 24         | 32         | 40         | 56         |
| d. SCBA, 742                                  | 25                   | DOP          | 4                                                                         | 4           | 24         | 40         | 72         | 96         | 96         |
| 3. Sierra                                     |                      |              |                                                                           |             |            |            |            |            |            |
| a. A-P, Welsh                                 | 35                   | NaCl         | 31                                                                        | 49          | 51         | 69         | 83         | 83         | 89         |
| b. S-A, Globe                                 | 25                   | DOP          | 0                                                                         | 0           | 0          | 4          | 12         | 20         | 28         |
| c. SCBA, Globe                                | 25                   | DOP          | 0                                                                         | 0           | 8          | 12         | 40         | 48         | 56         |

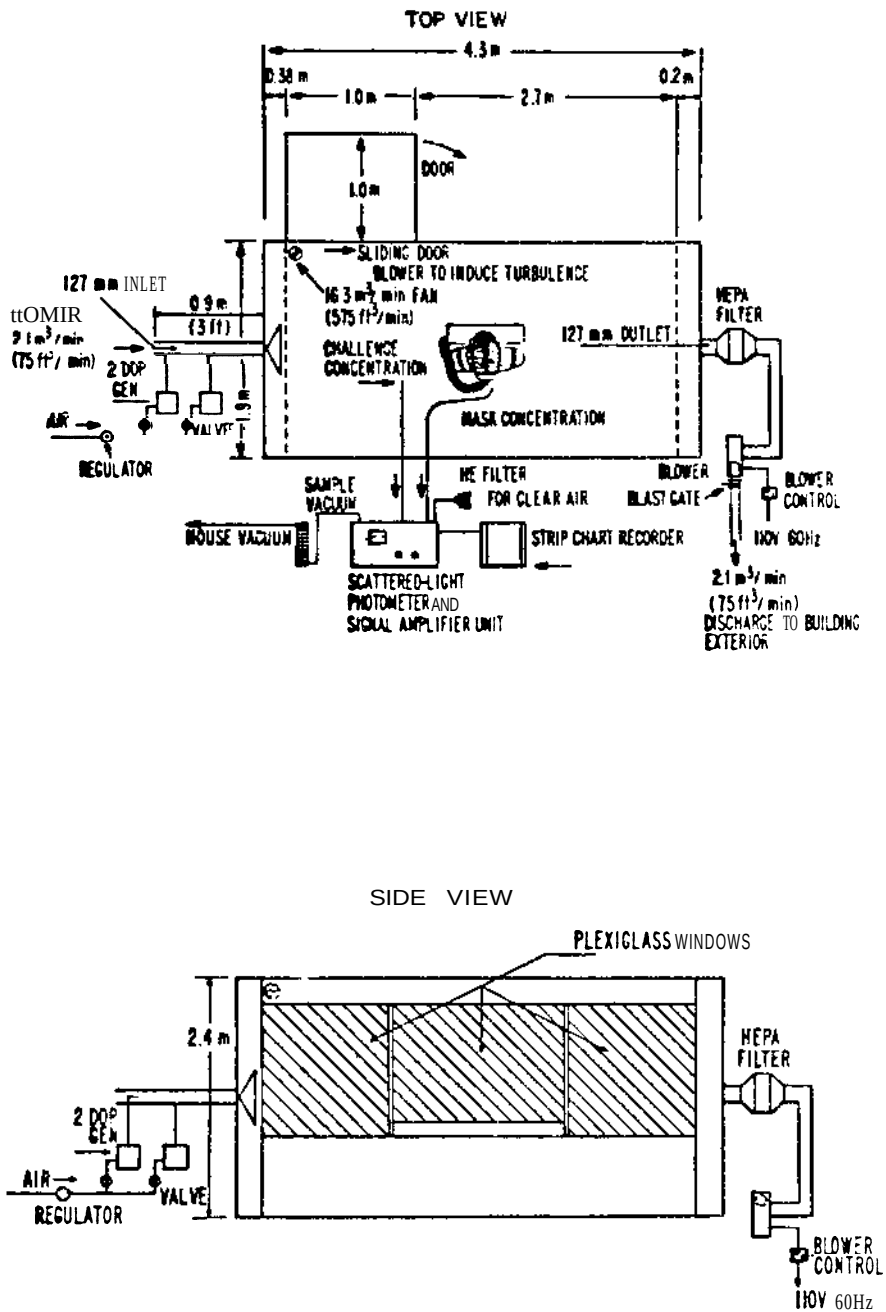


Fig. 1  
Schematic diagram of LASL DOP aerosol respirator  
quantitative fit-test chamber.

[Fran Lowry, et al (1978), with permission]

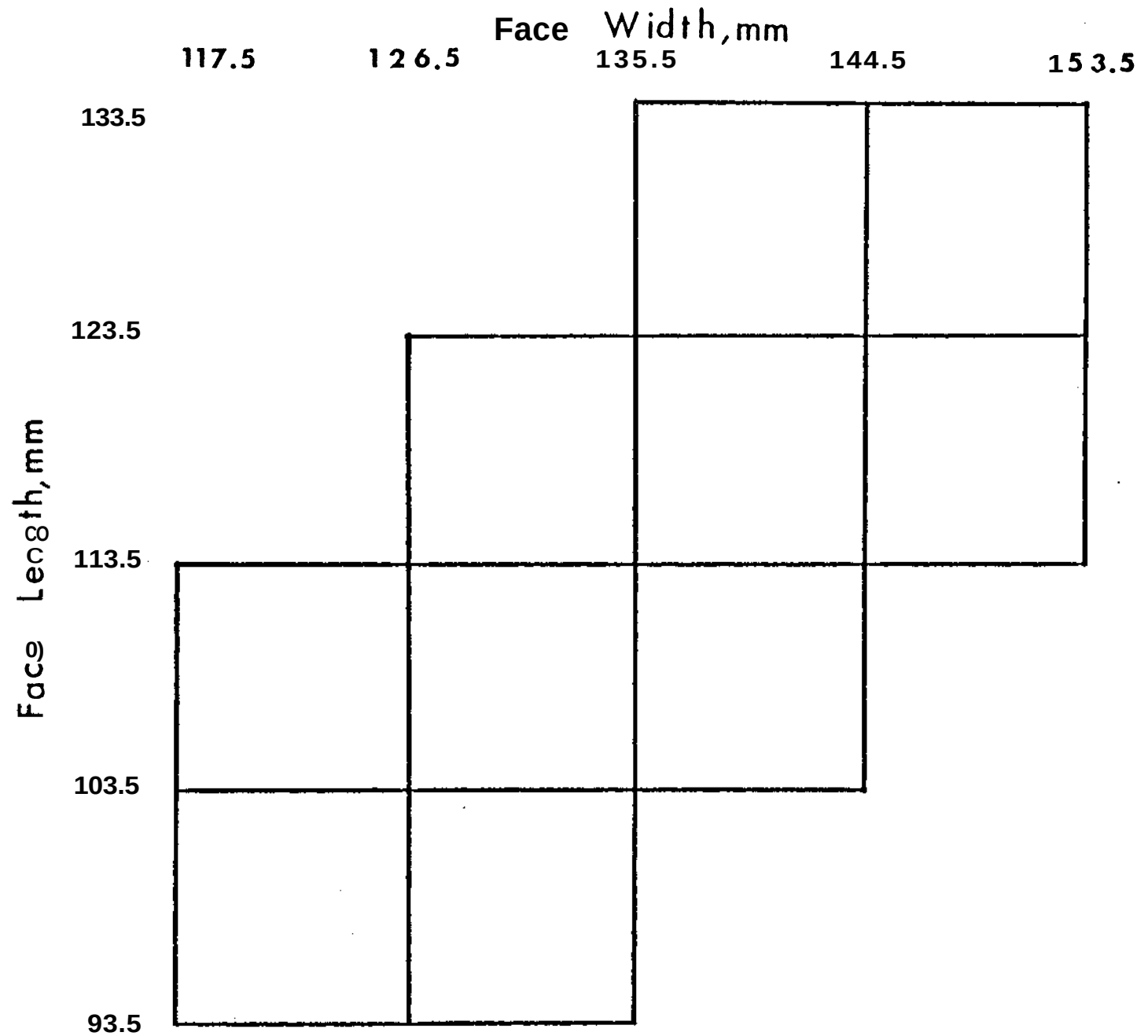


Fig. 2. Full Facepiece Test Panel Dimensions

[From Hack, et al (1973) and Hack, et al (1978), with permission]