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Respiratory Studies for the National Institute for Occupational Safety and Health July 1, 1972, through June 3, 1973

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RESPIRATORY STUDIES FOR THE NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH JULY 1, 1972 THROUGH JUNE 3, 1973

by

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John A. Pritchard, Bruce J. Held, Darell A. Bevis, Thomas O. Davis, Louis A. Geoffrion, Alan L. Hack, Philip L. Lowry, Tom O. Moore, Charles P. Richards, and Lloyd D. Wheat

ABSTRACT

Following is a summary of the progress of research and development activities performed during FY 1973 by the Respirator Research and Development Section, Industrial Hygiene Group of the Los Alamos Scientific Laboratory (LASL) under an interagency agreement between the National Institute for Occupational Safety and Health (NIOSH) and the Atomic Energy Commission. The work was done at LASL and was a continuation of the services performed for NIOSH by the AEC under an FY 1972 interagency agreement. As requested in the FY 1973 interagency agreement, the efforts were concentrated in three major areas: 1) The development of quality control test methods and the correlation of these test methods with the present respirator approval tests in order to provide improved quality control test methods for use by respirator manufacturers and NIOSH. 2) The design, construction, and delivery of respirator test equipment for the performance of quality control tests to the NIOSH Testing and Certification Laboratory at Morgantown, West Virginia, and to the NIOSH Engineering Laboratory at Cincinnati, Ohio, and 3) Develop respirator test methods.

I. INTRODUCTION

The respirator studies for the NIOSH were covered in two memorandums of agreement, LASL Project No. R061 and R072. Project R061 (3-1-72 through 2-28-73) requested LASL to develop dust and fume respirator-man test equipment and methods, 2) conduct anthropometric studies and selection of test panel, and 3) participate in meetings requested by NIOSH. Project R072 (FY 1973) was to design, construct, calibrate and deliver to Morganton, W. V. (NIOSH) by October 31, 1972, the following equipment; 1) one polydisperse DOP aerosol man test system, 2) one polydisperse DOP aerosol filter test system, and 3) one NaCl aerosol man test system. Additional services requested by the NIOSH were 1) to review manufacturer's quality control plans, 2) make recommendations for respirators for specific NIOSH Criteria Documents, and 3) assist in preparation of amendments to 30 CFR Part 11.

Additional lower priority services specified in the two NIOSH projects were: 1) conduct research to develop man test equipment and methods to evaluate all types of respiratory protective devices, 2) perform man tests on test subjects selected by approved anthropometric specifications, 3) construct and deliver to NIOSH by July 1, 1973, the following equipment: a) one NaCl aerosol filter test system, b) one polydisperse man test system, c) two dynamic valve test systems, d) one filter breathing resistance test system, and e) one head harness test system.

A top priority for review and comments on QC plans was required because respirator manufacturers had submitted over 20 different types of respirators for approval under Part 11, including approval of QC plans for each respirator. Since only one QC plan had been approved, assistance was needed.

During the NIOSH - B of M - Webb Associates - LASL Conference on September 14, 1972, approval was given to the LASL report on the anthropometric survey and method of selecting a representative test panel. It was requested that the report (with consultation by Webb Associates) be completed by December 4 for a joint conference with respirator manufacturers.

Recommendations for respirator protection for NIOSH Criteria Documents were made. A respirator selection guide was proposed for use in recommending respirators for criteria documents.

II. DEVELOPMENT OF TEST AEROSOL

A. Introduction

The development of the aerosols used in the two systems delivered to NIOSH this year has entailed a great amount of work of a basic nature. The work was necessary to ensure that we had aerosols which were reproducible in the particle size range and concentration desired for use in filter efficiency and quantitative man testing.

Historically, the first LASL NaCl aerosol system was built in 1968.[1,2] This bench model system used the Vokes Ltd. design of the Collison aerosol generator.[3] Since that time several further modifications of the original system have been made and several other types of aerosol generators used. The culmination of these efforts has been the LASL Model I NaCl aerosol System.

B. Sodium Chloride Aerosol

1. Methods of Aerosol Generation

By the first of this fiscal year, the decision had been made to use the Wright design nebulizer in the Model I NaCl system.[4] However, evaluations were made of seven other types of NaCl generators to ensure that the Wright design was the most suitable. A complete listing is as follows:

a. Vokes Ltd. version of the Collison atomizer.
b. British Standard (BS) 4400 nebulizer.[5]
c. DeVilbiss Model 800 Ultrasonic Generator.[6]
d. RETEC Model X-70/N nebulizer.
e. Dautreband D-30 nebulizer.
f. Lovelace design nebulizer.[7]
g. Macrosonics Inc. Ultrasonic Nebulizer.

All of the above were not considered satisfactory due to a variety of reasons, such as unsuitable aerosol characteristics, too high or low mass output, or general difficulty in interfacing the generator mechanically with the rest of the Model I system. The only one of this group which still shows promise is the BS 4400 generator. With some minor modifications, it would probably be adaptable to the purpose.

2. Methods of Particle Size Determination.

It became apparent during the year that most of the variations in NaCl particle size determination data could be traced to inconsistencies in the electrostatic precipitation method of particle size analysis and not the aerosol itself. Alternate methods of analysis, the spiral centrifuge aerosol spectrometer, and a set of single stage impactors were tried instead of the electrostatic precipitator.

In general, the results obtained by these methods have been more reproducible. Additionally both the spiral and the impactors give a direct measurement of the aerodynamic mass distribution of particle sizes, which is an advantage when considering the efficiency of the respirator against particle sizes which present a physiological hazard. Most lung deposition information is based upon the aerodynamic behavior of the particles. With this in mind, all of the LASL particle sizing data is now being reported in terms of the mass median aerodynamic diameter (MMAD) and the geometric standard deviation (σg). The electrostatic precipitator method of sizing determines a projected area diameter which must be mathematically converted to the aerodynamic diameter.

The disadvantages of both the spiral centrifuge and the electrostatic precipitator methods is that they require the use of expensive, fairly sophisticated equipment and skilled operators. Furthermore, the analyses are time consuming. To overcome these disadvantages, a set of four single stage impactors were designed and fabricated for use in routine determination of NaCl aerosol characteristics. These impactors designed by Marvin Tillery, Aerosol Section, Industrial Hygiene Group, LASL, are shown in Figures 1 and 2. They have predicted cutoff diameters of 2.81, 1.30, 0.58, and 0.24 μm when operated at a flow rate of 3 lpm. To determine a NaCl aerosol distribution, the four stages are sequentially inserted between the aerosol source and the peristaltic sampling pump in the Model I system as shown in Figure 3. The percent mass passing each stage is determined by the Model I flame photometer in a manner similar to that used for determination of filter efficiency. An analysis can be made in about 15 minutes including cleaning of the impactors and plotting of the data.

It was discovered that because of the high pressure drop across the 0.24-μm stage, a 3-lpm flow rate could not be obtained with the peristaltic pump. The flow rate on this stage was subsequently lowered to 2.6 lpm, which raised the predicted cutoff diameter to 0.28 μm. This did not decrease the usefulness of this method.

Table I summarizes all of the spiral centrifuge, electrostatic precipitator, and 1x4 Cascade impactor analyses made on the several Model I NaCl systems. Most of the impactor runs were made early in FY 1974 and are included for completeness. Analyses on three groups of Wright nebulizers and five NaCl aerosol systems are included in these data. Figure 4 shows the dimensions of four Wright-designed nebulizers. The LASL built, Wright-designed nebulizer has been installed in all the Model I systems. The Wright numbers 3 and 4 nebulizers were bought from British supplier. The Chalk River, Wright-designed nebulizer was the one originally loaned to us for evaluation by Mr. J. White of the Chalk River Nuclear Laboratory, Chalk River, Canada.

The data in Table I shows a reasonable correlation between the spiral centrifuge and the 1x4 Cascade impactor results while the electrostatic precipitator results are generally higher. It is suspected that a bias toward the larger particles was inadvertently introduced in the electrostatic precipitator analysis procedure, or in the mathematical transformation between the projected area diameter and the aerodynamic diameter.

The coefficients of variation in the MMAD's of the spiral and impactor analyses are acceptable except for the spiral data on the LASL fabricated nebulizers. Two analyses had higher than normal MMAD's. Although these data were in doubt, there was nothing discovered which justified eliminating these runs from the summary. Without these two runs, the spiral data comes much closer to the impactor data.

The larger coefficients of variation on the standard geometric deviation, as determined by the impactor, are due to the fact that only four points are used to establish the straight line plot on log probability paper. This permits a greater latitude in plotting than other methods which utilize many more data points.

During the coming year, the application of these impactors will be expanded. To reduce the variation in the geometric

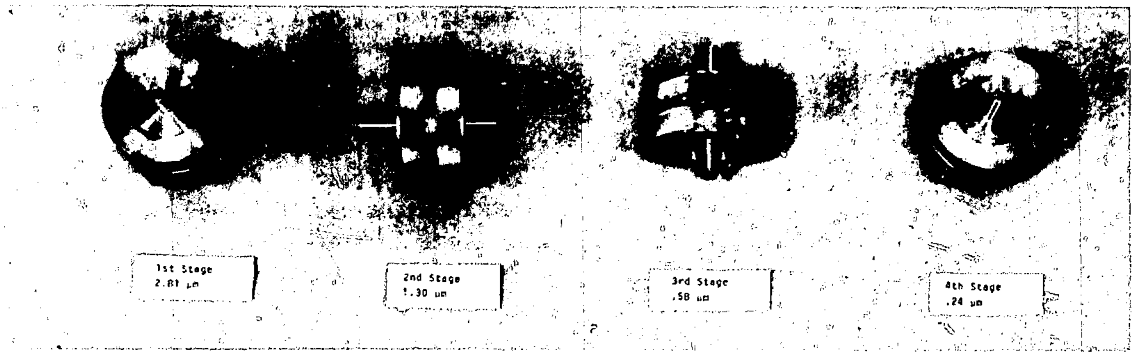


Fig. 1. The Tillery-Designed Single Stage Impactors Assembled.

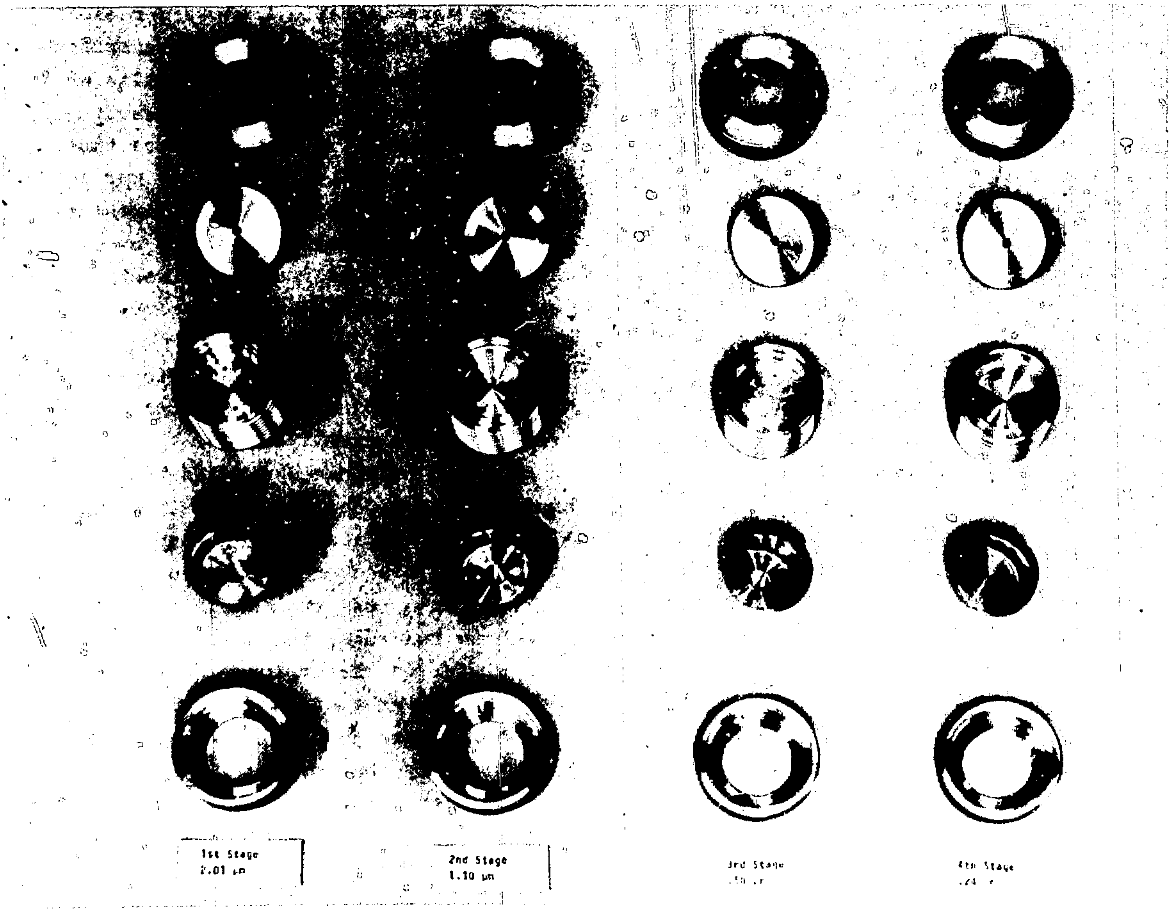


Fig. 2. The Tillery-Designed Single Stage Impactors Disassembled.

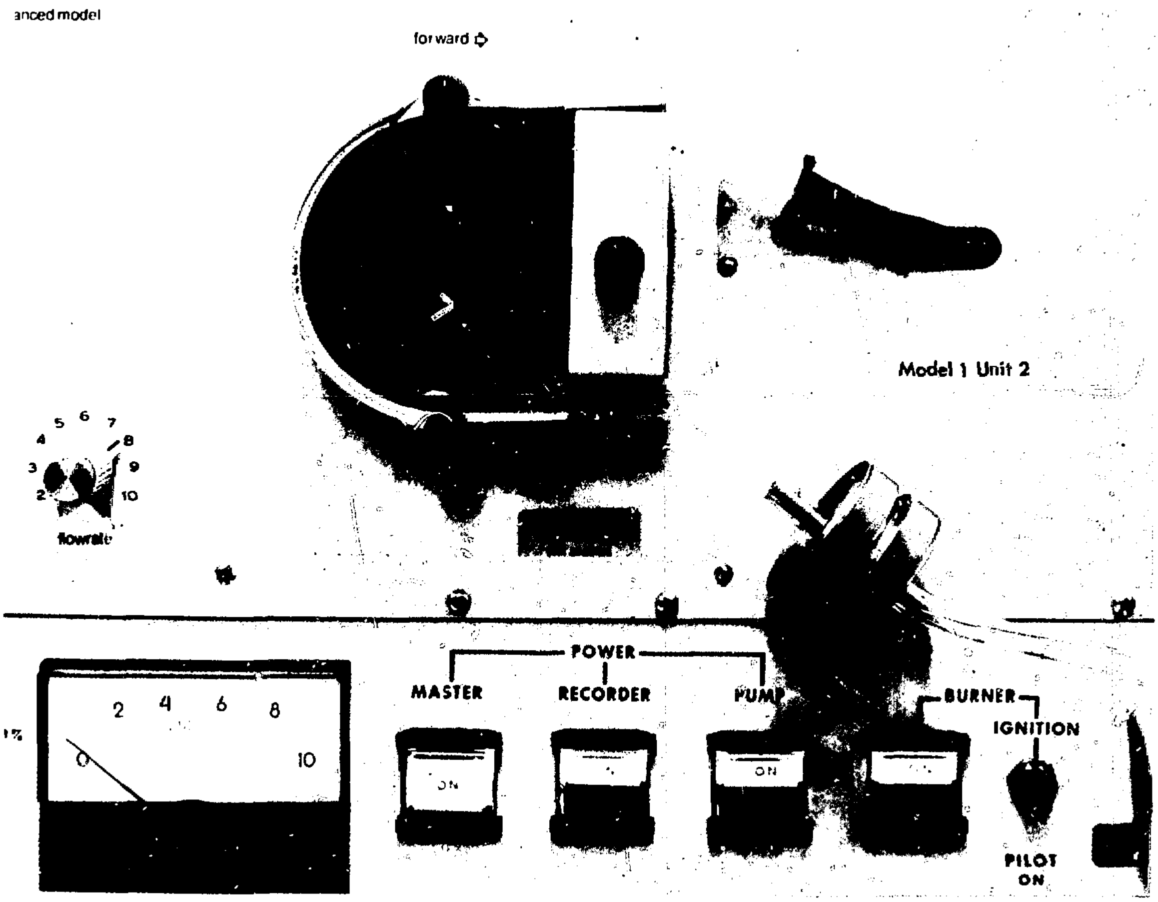


Fig. 3. Single Stage Impactor on the LASL Model I NaCl System.

standard deviations, predicted cutoff diameters will be calculated for each stage at flow rates other than 3 lpm. In this way, many more points can be obtained to establish the aerosol distribution plots while using the same four impactors. Furthermore, this same concept can be used in conjuntion with the TSI Particle Mass Monitor. It is proposed that a new set of impactors be designed to operate at the 1-lpm flow rate of the TSI. This would provide a means of quickly determining the aerosol characteristics of the silica dust and lead fume.

III. TEST EQUIPMENT

A. Introduction

According to the NIOSH/AEC memorandum of agreement for FY 1973, LASL was requested to deliver the following test equipment to the NIOSH Testing and Certification Laboratory, Morgantown, West Virginia.

1. One polydisperse dioctyl phthalate (DOP) aerosol man test system including exposure chamber and recorder for measuring the overall performance of particulate filter respirators.

2. One polydisperse DOP aerosol filter test system including filter test chuck and recorder.

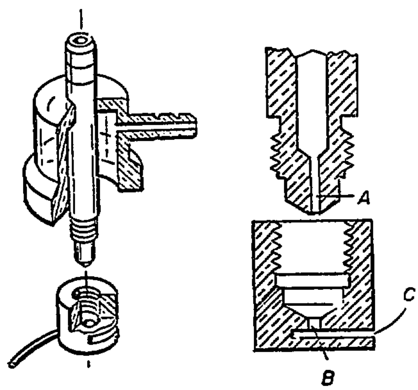
3. One combined polydisperse DOP aerosol man/filter test system including exposure chamber, filter check, and recorder.

TABLE I

DETERMINATION OF NaCl PARTICLE SIZE DISTRIBUTION
WRIGHT DESIGNED NEBULIZERS OPERATED
AT 165 KPA WITH A 1% NaCl SOLUTION

Method of Determination	No. of Analyses	No. of Different Systems Tested	No. of Different Nebulizers Tested	AMMD Mean (μm)	AMMD Std. Dev. (μm)	AMMD Coeff. of Var. (%)	σg Mean	σg Std. Dev.	σg Coeff. of Var. (%)
			LASL FABRICATED WRIGHT-DESIGNED NEBULIZERS						
Spiral Centrifuge	10	5	5	0.80	±0.14	±17.5	2.47	±0.19	± 7.7
Electrostatic Precipitator	3	1	2	1.09	±0.15	±13.8	3.00	±0.39	±13.0
1x4 Cascade Impactor	23	2	3	0.72	±0.06	± 8.3	2.45	±0.36	±14.7
			"CHALK RIVER" NEBULIZER						
Spiral Centrifuge	2	1	1	0.68	±0.02	± 2.9	2.23	±0.09	± 4.0
Electrostatic Precipitator	4	1	1	0.72	±0.10	±13.9	1.79	±0.21	±11.7
1x4 Cascade Impactor	6	1	1	0.625	±0.01	± 1.6	2.06	±0.23	±11.2
			PURCHASED WRIGHT NEBULIZERS						
Spiral Centrifuge	5	2	2	0.86	±0.02	± 2.3	2.24	±0.40	±17.9
Electrostatic Precipitator	1	1	1	1.09	---	---	2.94	---	---

WRIGHT NEBULIZER



Critical Dimension

Nebulizer	A mm	A in.	B mm	B in.	C mm	C in.
Chalk River	0.787	0.031	1.499	0.059	0.864	0.034
Wright No. 3	0.864	0.034	1.608	0.063	1.115	0.044
Wright No. 4	0.848	0.033	1.603	0.063	1.115	0.044
LASL Built (Nominal)	0.742	0.029 (1/32)	1.585	0.062 (1/16)	1.156	0.046

Fig. 4.

4. Two sodium chloride man test systems for respirator facepiece leakage tests including exposure chambers and recorders.

5. Two dynamic valve test systems including all auxiliary equipment.

By mutual agreement with NIOSH, the construction and delivery of item 3, the combined polydisperse DOP man filter test system was deleted. In item 4 only one sodium chloride system was delivered to TCL. The second NaCl system was constructed but has been kept for use at LASL until needed by NIOSH. The two dynamic valve test systems were deleted, again by mutual agreement. The development and construction of these systems was moved into FY 1974.

Additionally, LASL was requested to construct and deliver the following test equipment to the NIOSH Engineering Laboratory, Cincinnati , Ohio:

1. One combined polydisperse DOP Aerosol man filter test system including exposure chamber, filter chuck and recorder.

2. One dynamic valve test system including all auxiliary equipment.

The dynamic valve test system was not constructed and the work has been moved into FY 1974, with approval of NIOSH. The polydisperse DOP system was delivered as well as a sodium chloride aerosol system required under the FY 1972 memorandum of agreement. The construction, check out, and calibration of these systems consumed a large share of the efforts during FY 1973.

B. LASL Model I NaCl Aerosol System

The design and construction of the first Model I NaCl Aerosol Systems was done during FY 1972. Three more units were built during FY 1973. The design of the aerosol generation system was based on work with NaCl aerosols done at LASL since about 1968. The flame photometer design was an adaptation of the Baird Atomic KY-4 Flame Photometer burner to the LASL Model 69B forward light scattering photometer electronics system.[8]

A photograph of the LASL Model I NaCl Aerosol System is shown in Figure 5 and a flow diagram is shown in Figure 6. The system consists of two major sections, the aerosol generation and dilution section, and the flame photometer section. The two sections are contained in a standard 48 cm (19 in.) electronics cabinet measuring 66 cm (26 in.) wide by 65 cm (25.5 in.) deep by 133 cm (52.5 in.) high. The cabinet is mounted on wheels. The chimney enclosing the opening over the flame photometer burner extends approximately 46 cm (18 in.) above the top of the cabinet. The system weighs approximately 113 kg (250 lb).

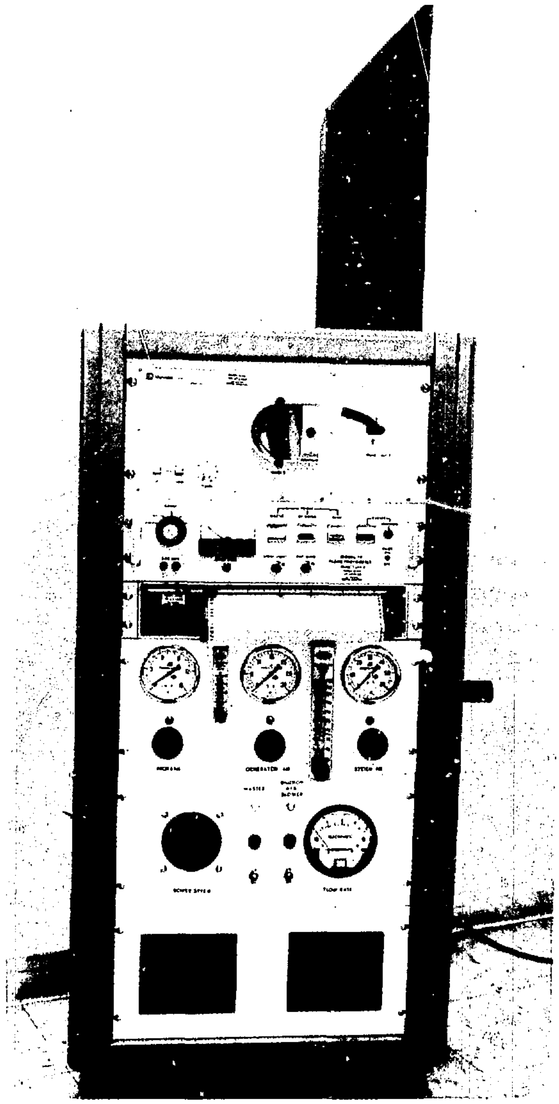


Fig. 5. LASL Model I NaCl Aerosol System.

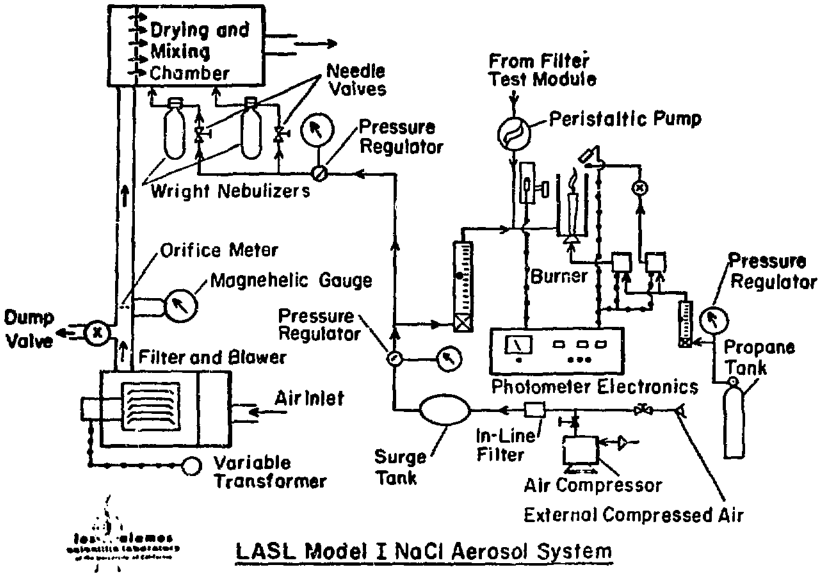


Fig. 6.

The NaCl aerosol is produced by the two Wright design nebulizers shown in Figure 7, mounted on the side of the 22.9 x 30.5 x 55.9 cm (9 x 12 x 22 in.) polyethylene mixing and drying chamber. The nebulizers inject the atomized NaCl solution perpendicularly to the drying air stream. The nebulizers are normally operated singly at 165 kPa (24 psi) input pressure, although both can be used to obtain a higher concentration at approximately the same total aerosol flow rate or a higher flow rate at the same concentration.

The air for drying the aerosol is supplied through a two stage centrifugal blower ahead of which is mounted a 20.3 x 20.3 cm (8 x 8 in.) high efficiency (HEPA) filter. The air flow rate is determined by an orifice meter and magnehelic gauge and is controlled by a variable transformer connected to the blower. A dump valve immediately upstream from the blower outlet can be opened to bypass a portion of the blower output to the atmosphere when very low drying air flow rates are desired. This allows the blower to be operated at a higher, more stable voltage.

The compressed air supply for the operation of the nebulizers and combustion air for the flame photometer burner is provided, either from an internally mounted air compressor or from an external source.

A small in-line filter removes particulate contaminants from the air stream and a surge tank dampens pulsations in the flow. A pressure regulator downstream from the air receiver provides a first stage reduction to the 276-345 k Pa (40-50 psi) needed to operate the system. A second regulator reduces the pressure to the generator operating pressure. The combustion air supply, normally 4.01 x 10^{-4} m^3/s 50 CFH, is controlled and measured by a combination flowmeter-needle valve.

The propane for the flame photometer is supplied from an external tank for safety reasons. The pressure, 62-69k Pa (9-10 psi), is controlled through a regulator on the front panel with the regulator on the tank set somewhat higher. Although the propane supply can be shut off, either with the pressure reducing valve or the needle valve on the flowmeter used to control the propane flow, normal procedures are to shut off the

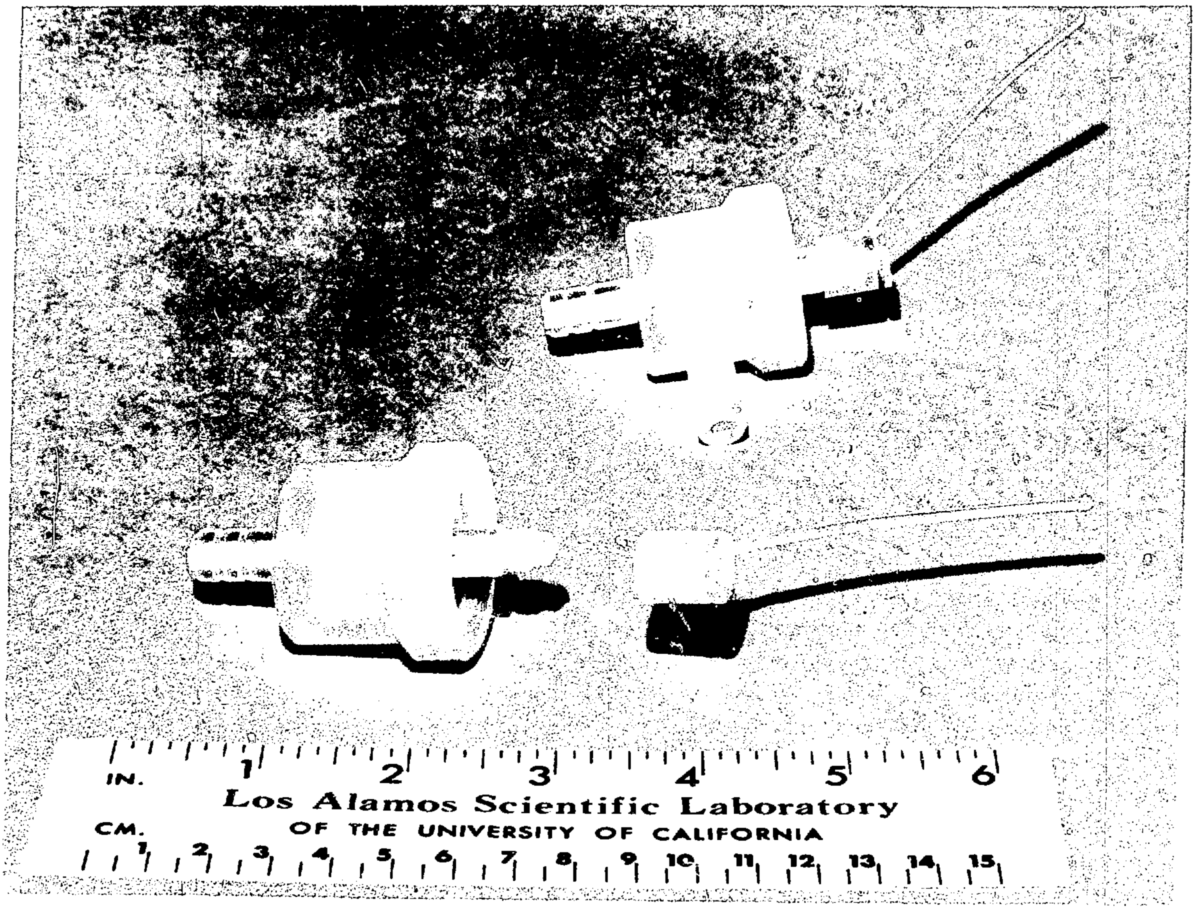


Fig. 7. LASL Built Wright Nebulizers.

propane at the tank to avoid leaving the supply lines inside the cabinet pressurized when the system is inoperative. The propane flow rate is nominally 1.2 x $10^{-5}m^3/s$ (1.5 CFH). Pure grade propane (99% mol minimum) is used although less pure grades can be used with resulting increase in the stray light compensation necessary due to impurities in the propane which affect the flame.

The burner assembly and phototube was purchased from Baird Atomic, Inc., and includes a 1P21 photomultiplier tube (PMT) which views the flame through a neutral density Na interference filter which has a peak response of 589.5 nM and a bandwidth of approximately 10 nM at 50% transmission.

A Fisher Manostat variable speed peristaltic pump is used for sampling the NaCl aerosol. This pump has the capabilities of delivering in excess of 3 lpm to the burner against a significant resistance. Testing of respirator filters is normally done at a 5.0 x $10^{-5}m^3/s$ (3 lpm) sampling rate and quantitative man testing is at 1.67 x 10^{-5} m^3/s (1 lpm).

No major modifications of the system are planned at the present time. Our experience during the testing of dust and fume respirator filters and quantitative man testing of dust respirators has proven the system to be reliable and easy to operate. Comparative test results of initial filter penetration using different units in the hands of different operators have been satisfactorily reproduced.

During the coming year the practical operational limits of this system will be determined by 1) varying generator operating pressures, 2) NaCl solution concentrations, 3) dilution airflow rates, and 4) the relative humidities of the dilution air to determine the growth of particle size due to increased humidity. The operating conditions will be generally restricted to a generator operating pressure of 165 kPa (24 psi) and a 1% NaCl solution.

Some question has arisen concerning the accuracy of NaCl penetrations less than 0.1% on quantitative man tests. A slight depression in photometer response has been observed, evidently due to some constituent in the exhaled breath. The depression is estimated to be less than 0.05% penetration and therefore practically can be ignored for observed penetrations greater than 1% as this would introduce an error of <5% in the data. However, quantitative man test results on high efficiency respirators should not be relied upon until the source of this interference can be ascertained. Fortunately, most respirators are not of this type. Efforts will be made this coming year to solve this problem.

At the moment, this system, used in conjunction with a quantitative man test hood, is suitable for evaluation of the overall efficiency of respirators equipped with dust and fume filters. When used with a filter test module, it provides a fast, reproducible, and non-destructive method of evaluating the initial filter efficiency and loading characteristics of dust and fume respirator filters.

A paper describing the use of this system and the filter test module in evaluation of dust and fume filter efficiency was given at the 1973 AIHA Conference in Boston.[9] A formal report is being prepared describing the LASL Model I NaCl Aerosol System in detail for publication both as a LASL and a NIOSH document and also in the AIHA Journal. An operating manual for this system has been written and distributed.

C. LASL Model A Polydisperse DOP Aerosol System

The LASL Model A Polydisperse DOP Aerosol System has been described in some detail in a previous report[10] as the first of these units was built during FY 1972. During this year additional systems were constructed and delivered to NIOSH, and one modification was made to the original design. The first unit contained the rectangular slot impactor described by Echols and Young.[11] This impactor was replaced with a round jet impactor, designed by Ron Stafford of the H-5 Aerosol Section, which theoretically has sharper cutoff characteristics than the rectangular jet.

The use of the system in conjunction with the filter test module for determination of initial filter efficiency is restricted to non-degradable (i.e. mechanical-type) filters. The DOP aerosol rapidly degrades the resin-impregnated wool felt filters. In conjunction with the test hood, the system can be used for quantitative man testing of high efficiency filter respirators or self-contained breathing apparatus. Even though DOP has a threshold limit value[30] (TLV) of 5 mg/m^3, the exposure to the test subject for the approximately 10 minutes it takes for a test at the low leakages normally encountered with these devices (<1%) is minimal. (See Section VI, B5)

Two commercial polydisperse DOP aerosol units, with designs similar to the LASL Model A system, were evaluated. The Frontier Enterprises system was purchased, while the Air Techniques Incorporated system was returned to the manufacturer. The Frontier system was purchased, based on low bid and somewhat higher quality of construction.

D. Auxiliary Test Equipment

1. Filter Test Module. In order to provide the maximum amount of flexibility of operation, a separate filter test

module was designed to interface with either the Model I NaCl or the Model A Polydisperse DOP Aerosol System. The module permits either filter efficiency evaluation or determination of resistance to flow (pressure drop) measurements to be made on most types of particulate respirator filters. Two modules were constructed this year and delivered to NIOSH.

A photograph of the module is shown in Figure 8. The system is dependent on 110 VAC power and a source of compressed air to operate the filter test chuck. It is also dependent upon one of the aerosol systems for the test aerosol. Two separate airflow paths are provided as is shown in Figure 9. On the left side of the unit is a mechanism for determining the pressure drop across the test filter. The pressure drop is measured by inserting the test filter, mounted in a modified filter receptacle from the facepiece, into a holder in the top of the module. Air is pulled through the filter at the rates specified in 30 CFR Part 11.[12] The pressure drop is measured on a photohelic gauge or an incline gauge. The photohelic gauge has adjustable set points so that a go, no-go determination can be made when large groups of filters are quality-control tested. The incline gauge provides a more accurate measurement for research and development purposes.

Filter efficiency measurements are made using the air operated chuck on the right side of the unit. The aerosol is introduced into the top portion of the chuck. The required flow goes down through the test filter which is mounted in the same manner as that used for pressure drop testing. The excess aerosol is bypassed to the atmosphere. The pressure in the test chuck is kept as nearly ambient as possible to minimize inward and outward leakage.

The photometer sample is taken nearly isokinetically downstream from the filter. When the test chuck is open a back flow of clean air automatically introduced between the sampling point and the test chuck, prevents a high concentration of aerosol from swamping the photometer.

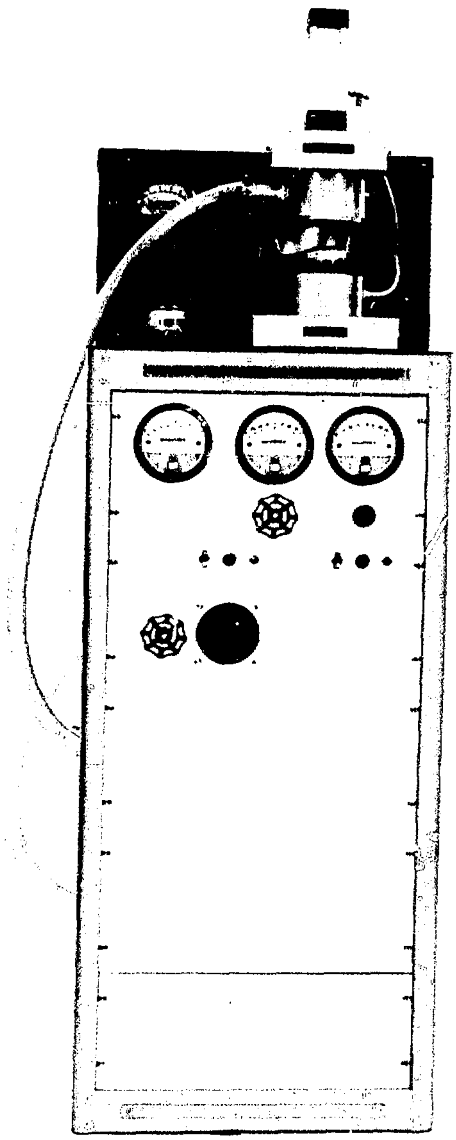


Fig. 8. LASL Filter Test Module.

All of the initial filter penetration tests and loading tests described in this report were made with the filter test module.

2. Quantitative Man Test Hoods. Three different sizes of hoods, all based on the design by Prof. William Burgess, Harvard School of Public Health, were constructed this year.[6] The first is a duplication of the Harvard design, consisting of a double walled cylindrical plastic enclosure, 76 cm (30 in.) in diameter. It has a rigid metal top plate with a built-in aerosol distribution system consisting of a perforated metal plate suspended approximately 5 cm (2 in.) below the top plate. The aerosol is introduced into the center of the top plate and exhausts between the two walls of the chamber through two openings on the outside edge of the top plate. This design is shown in Figure 10. The exhaust aerosol stream can be returned to the dilution air inlet in the aerosol system where it is cleaned before passing into the dilution air chamber. By keeping the exhaust air flow rate slightly greater than the inlet, aerosol leakage to the surroundings can be minimized. The excess airflow is dumped inside the aerosol system cabinet before it reaches the dilution air chamber.

The 76-cm (30-in.) chamber proved to be too small for testing the bulky self-contained breathing apparatus. Therefore, a 91-cm (36-in.) chamber was built along the same basic design. This hood, shown in Figure 11 is equipped with a supporting framework and power hoist, and was delivered to the NIOSH Testing and Certification Laboratory. Although satisfactory, the large volume of this chamber has presented some problems in maintaining a steady and uniform aerosol concentration, particularly at the normal 1.89 x $10^{-3} m^3/s$ (4 CFM) flow rate of the Model I NaCl system.

A third size hood, 84-cm (33-in.) was built which provides the room necessary for testing self-contained breathing apparatus. At the same time, it has the aerosol concentration stability of the small hood.

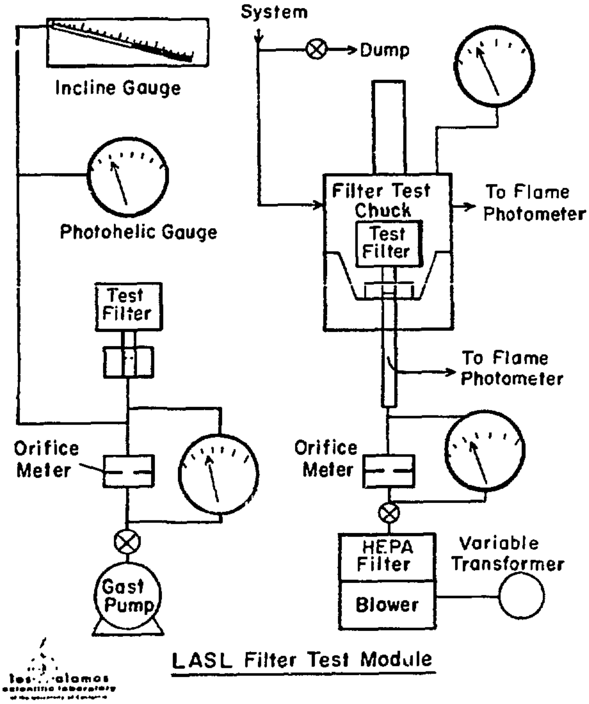


Fig. 9. LASL Filter Test Module Schematic.

E. Respirator Exhalation Valve Test System

Preliminary design work was done this year on a system to evaluate the performance of respirator exhalation valves. This work consisted principally of a review of the availability and suitability of instrumentation and establishment of test criteria. The construction of a bench model system will start in FY 1974.

In the preliminary design are the capabilities of determining exhalation valve leakage (volume/time) under both static suction and dynamic conditions using a breathing simulator pump. Provisions have also been made for determining leakage of the exhalation valve when challenged with various aerosols and gases, both under static and dynamic conditions.

F. Respirator Head Harness Test System

The development of a head harness test system has been of low priority, compared to the other work requested this year.

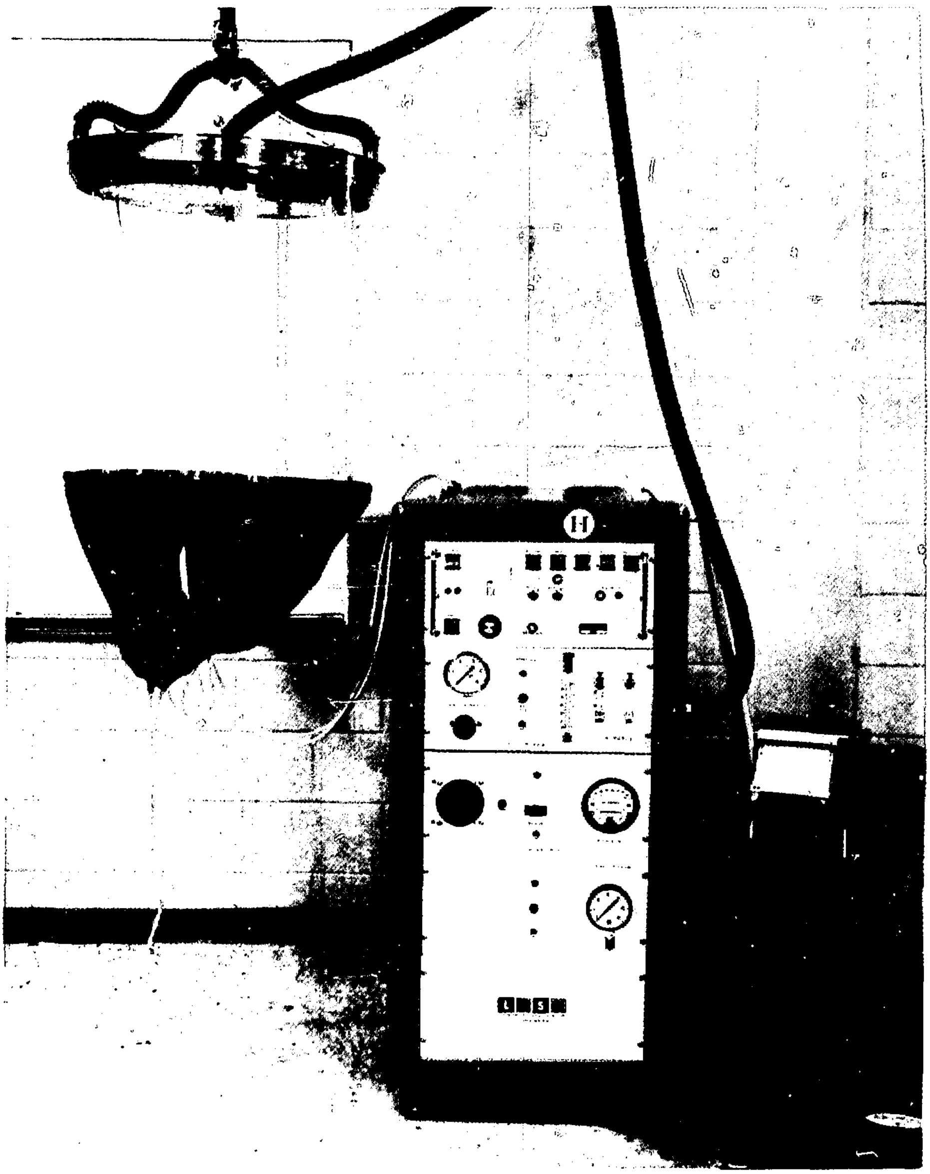


Fig. 10. Poly DOP Man Test System with the 76-cm Diameter Burgess-Designed Hood.

Therefore only a minimum amount of work has been done, consisting primarily of exploring methods of instrumentation. Further development of this system has been moved into FY 1974.

IV. DUST AND FUME FILTER EFFICIENCY MEASUREMENT

A. Introduction

During the first two years of this program, high priority has been given to the development of a sodium chloride aerosol respirator filter test system and methods to measure the efficiency of dust and fume filters. The LASL Model I system

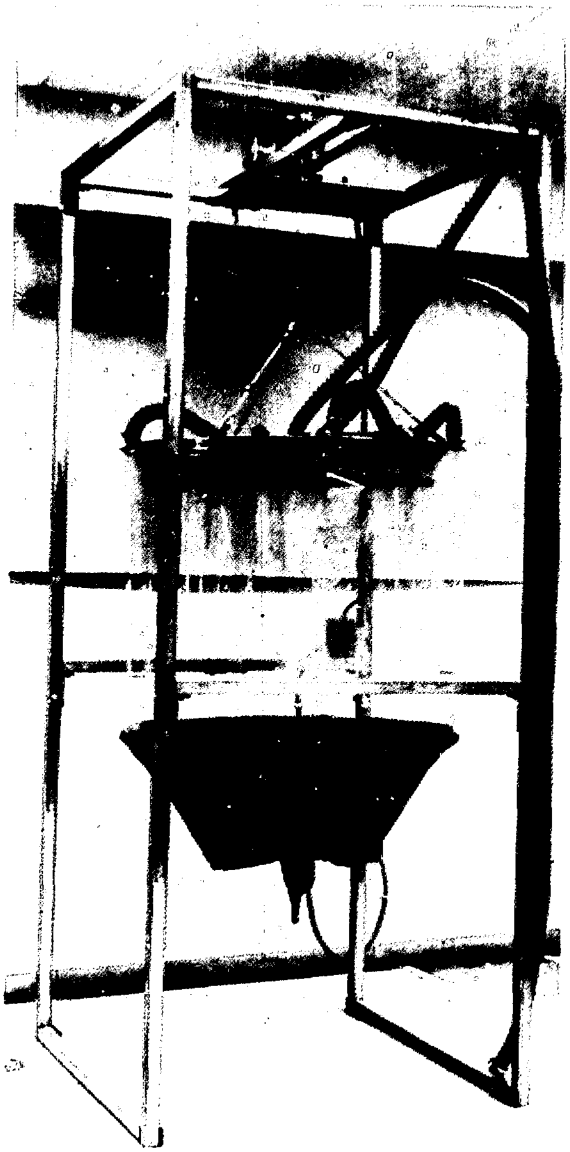


Fig. 11. 91-cm-Diameter Burgess-Designed Hood.

(see Section III) provides an accurate, rapid, reproducible and nondestructive method to measure the initial penetration and pressure drop of dust and fume filters made from the wide variety of filter media. By the start of FY 1973, the first LASL Model I system had been completed and initial filter efficiency and loading tests were run on several hundred dust and fume filters. The work done this year was to improve the filter test methods by performing filter efficiency, pressure drop, and loading tests on approved dust and fume filters.

B. Background Information

1. Introduction. During FY 1972, high priority was given to developing sodium chloride and DOP filter test systems and methods for quality control and to determine the correlation of these test methods with respirator approval tests. The silica dust test for approval of dust respirators and the lead fume test for approval of fume respirators specified in 30 CFR Part 11[12] were discussed in the first quarterly progress report[13] for FY 1972. To determine the correlation of the LASL filter test system with the silica dust and lead fume approval test, it was emphasized that initial filter penetration measurements would have to be made. Also, the particle size of the silica dust and lead fume needed to be determined.

The first comparative sizing study of the B of M silica dust aerosol was reported in the second quarterly progress report[14] for FY 1972. Initial filtering penetration tests using the B of M silica dust on four types of dust respirators were discussed in the third quarterly progress report[10] for FY 1972. These tests were made with a Thermal Systems Incorporated (TSI) particle mass monitor. These preliminary test data indicate initial filter measurements with silica dust by this method are feasible. The initial calibration of the TSI particle mass monitor against the LASL sodium chloride aerosol has been reported.[10]

2. Correlation of Filter Penetration: Silica dust vs. NaCl Aerosol. The results of a study to correlate the silica dust approval test with the initial sodium chloride aerosol penetration made on clean filters was reported[13] in FY 1972. A

cooperative study with W. Revoir of the AO Respirator R & D Lab with the AO-R 30 resin wool felt dust filter showed poor correlation. However, the increased penetration due to increased velocity by both silica dust and sodium chloride aerosols was verified. It was concluded that it is impossible to correlate the initial filter penetration measurement with the sodium chloride aerosol and the silica dust penetration measured after a 90-min test and a loading of approximately 160 mg of silica dust.

A more practical correlation study reported by Revoir[15] in 1971 compares the U.S. B of M silica dust approval tests with the United Kingdom (UK) sodium chloride aerosol (MMD = 0.6 μm) approval test. Five typical dust respirators approved in the UK and the US (3 US & 2 UK respirators) were tested by the approval test methods in the US and the UK. The dust filter penetration test made by the B of M silica dust aerosol on the five dust respirators showed that all met the approval requirements with no significant difference in silica dust penetration. However, the two UK respirators showed slightly less penetration.

The dust filter penetration tests made by the UK sodium chloride aerosol on the five respirators showed significant differences. For approval in the UK, the maximum penetration allowed for resin wool felt filters is 3.5% and 2% for resin wool batt filters. A Type B mechanical (non-degradable) filter is allowed a maximum of 5% penetration. Two of the US dust respirators with resin felt filters showed a penetration range of 2.2 to 7.2% and 0.4 to 6.2%, while a third US dust respirator with a mechanical filter showed a penetration range of 6.0 to 10.0%. The number of filters tested was not given (UK Standard specifies 8 filters). However, some of the US resin felt filters exceeded the 3.5% maximum allowed, and all of the US mechanical filters failed the 5.0% maximum allowed. However, the two UK dust respirators showed penetration ranges of 0.2 to 0.5% and 0.68 to 1.26%, indicating all filters passed the 2.0% maximum allowed.

In comparing the results of the joint UK-US study on five typical dust respirators, Revoir concludes that the approved dust respirators manufactured in the UK tend to be somewhat more efficient in removing airborne particulates than those manufactured in the US. This is significant when considering amendments to 30 CFR Part 11 and the proposed sodium chloride aerosol approval tests for dust and fume respirators. In comparing the initial resistance to inhalation, Revoir concludes that there is no significant difference by respirators manufactured in both countries. However, Revoir concludes that a comparison of the values for the initial and final resistance to inhalation offered by the five respirators tested against silica dust indicate that the filters from dust respirators made in the UK tend to plug less rapidly with retained particles than the filters from dust respirators manufactured in the US. This is significant when considering whether the silica dust and lead fume approval tests should be retained in the proposed amendments to 30 CFR Part 11 for dust and fume respirators. If the proposed sodium chloride aerosol approval test is adopted, the only purpose of including the silica dust and lead fume tests is to measure final resistance after loading.

The UK dust respirator approval test specifies a test for resistance to clogging by dust and humidity. However, this approval test is only made <u>if</u> the dust respirator is required to comply with the requirements for resistance to clogging by dust and humidity. This requirement is primarily for dust respirators used in coal mines. Based on the above discussion, it is logical to conclude that the silica dust loading test should only be required for respirators to be used in coal mines. The lead fume loading test should be eliminated.

<u>3. Factors Affecting Filtering Efficiency</u>. The factors affecting filtering efficiency include 1) particle size, 2) flow rate (velocity), 3) loading, and 4) degradation or loss of electrostatic charge by

resin felt filter media. Initial test data demonstrating the affect of all four factors on dust and fume filtering efficiency with DOP and sodium chloride aerosols were reported in FY 1972.[10, 13]

These initial filtering efficiency tests were made with two sizes of sodium chloride aerosols (MMD = 0.4 and 0.8 μm) in an attempt to simulate the relatively small lead fume and the large silica dust. All dust filter efficiency tests reported in FY 1972 were made with the 0.8 μm sodium chloride aerosol and fume filter efficiency tests with the 0.4 μm sodium chloride aerosol. Comparative fume filter efficiency tests were also made with a monodisperse 0.3 μm DOP aerosol and a polydisperse 0.8 μm DOP aerosol. The test data on approximately 100 MSA and Welsh fume filters reported[10] were plotted to graphically illustrate quality control tests with two sizes each of the sodium chloride and DOP aerosols.

The degradation of resin wool felt filters by the two sizes of liquid DOP aerosol and two sizes of solid sodium chloride aerosol also were reported.[10,13] These results indicated that the degradation of resin wool felt is more rapid by liquid DOP aerosols than by solid sodium chloride aerosols. Also, degradation by liquid DOP aerosols is irreversible, while a solid sodium chloride aerosol degrades resin wool only to a point where the solid aerosol loading reverses the degradation and the penetration decreases to less than 1.0% for all types of resin wool felt dust filters. Results reported by Kaufman[16] in 1968 demonstrated that water vapor (RH = 95%) in mine atmospheres sampled continuously through resin wool batt degrades the same as the liquid DOP aerosol. With a high concentration of diesel fume, the degradation was reversed after a few hours and the penetration decreased.

4. Steady vs. Cyclic Flow Filter Efficiency Measurements. The accuracy of steady flow dust and fume filter approval tests specified by US and UK approval schedules has been questioned because it is not cyclic or pulsating flow, which represents use conditions. In a recent study of European dust respirator approval testing, Luxon[17] reports that four countries are using a pulsating flow test for approval of dust respirator filters.

In 1971 the LASL Aerosol Section initiated a study of respirator filter efficiency under cyclic and steady flow conditions. In the initial report on this continuing study, Stafford[18] concluded that filter efficiency measurements with steady flow rates overestimates the efficiency of the respirator filter as it would normally be used. Stafford stated that steady flow rates overestimates the filter efficiency at particle sizes below 0.3 μm and above 1.2 μm. He noted that particles larger than 1.2 μm are of considerable significance because of their mass, which is still respirable. Stafford used a liquid 0.3 μm DOP aerosol and several sizes of solid polystyrene latex aerosols to study the MSA and Welsh fume filters.

During FY 1973, the study of dust and fume filter efficiency under cyclic and steady flow conditions was continued by Tillery of the LASL Aerosol Section. Tillery will report the results of this study by the end of FY 1974. Until that time, no recommendations will be made regarding the currently proposed steady flow rates of 16 lpm and 32 lpm for dual and single filter cartridges, respectively.

C. Initial Fume Filter Penetration: Pb Fume vs. NaCl

During the first half of this year, two trips were made to the B of M in Pittsburgh to use the lead fume chamber to evaluate the initial efficiency characteristics of fume filters. The initial sodium chloride aerosol penetration of the test filters were determined at LASL, and then pairs of these same filters, mounted on facepieces, were connected to the lead fume chamber. The upstream and downstream aerosol concentrations were made with the TSI particle mass monitor. A comparison of these test results is shown in Table II. The initial sodium chloride aerosol penetrations shown are an average of the two filters. Each pair was as closely matched as possible as to the initial sodium chloride penetration. Generally, there is a correlation between the two sets, although more testing will have to be done to substantiate the findings.

TABLE II

COMPARISON OF INITIAL FILTER PENETRATIONS

Pb Fume vs. NaCl

Type Filter	Initial Penetration, % Pb Fume(1)	NaCl(2) (3)
AO-R56	3.52	5.45
	4.83	4.75
	4.75	4.15
	2.75	4.90
MSA "S"	1.33	1.55
	1.37	1.55
	1.27	1.48
	1.30	1.38
	0.50	1.30
	1.59	1.55
Willson R-11	0.36	0.50
	0.06	0.15
	0.25	0.85

(1) Penetrations determined with TSI Particle Mass Monitor.

(2) Penetrations determined with LASL Model I NaCl System, using 0.6 ± 0.1 μm MMAD NaCl aerosol with a σ_g <2.25.

(3) Apparent NaCl penetration, assuming linear response for flame photometer as a function of NaCl aerosol concentration. Recent data indicate that this assumption is not completely correct.

It must be pointed out that the NaCl filter penetrations in Table II and the sections following in this report may be in error. Recent work (1974) has shown that the response of the flame photometer to changes in aerosol concentration within the burner chimney is not linear due to self-absorption in the flame at higher aerosol concentrations. The effect of this is that the photometer will indicate higher apparent penetrations than by other measurement methods, such as gravimetric or chemical analysis.

We are correcting this problem by lowering the aerosol concentrations in the chimney. Attempts will be made to develop a correction curve for the data presented in this report.

As an outgrowth of the preliminary tests for initial filter penetrations of lead fume, it was possible to obtain some preliminary data on the loading characteristics of the filters. The results of two tests on the AO R-56 fume filter is shown in Figure 12. These preliminary data indicate that the lead fume decreases the penetration very rapidly, similar to other metal fumes.

D. Results of Dust and Fume Filter Efficiency Tests

We believe it is desirable to use a single size standard sodium chloride aerosol to compare the filter efficiency of dust and fume filters. Therefore, all of the initial filter efficiency test results on approved dust and fume filters during FY 1973 were made with a 0.6 μm MMAD sodium chloride aerosol at a concentration of approximately 15 mg/m^3. The flow rates through the filters were either 16 lpm for filters normally used in pairs, or 32 lpm for filters used singly. The initial resistance to breathing was also measured on all dust and fume filters, at a flow rate of 42.5 or 85 lpm, for filters used in pairs or singly, respectively.

The large accumulation of filter efficiency test data has made it desirable to store this information in the LASL computers. Two retrieval programs permit the display of the stored information in several ways, both tabular and graphical.

Most of the filter testing has been on relatively large lots of filters, as described previously. An individual test filter can be identified by a LASL test lot number plus the number of that filter within the lot. The LASL lots are further identified by the type of filter (dust, fume, etc.), manufacturer, and testing date.

The filter test data have been divided into two main groups: 1) by percent penetration, and 2) by percent penetration and pressure drop. The first retrieval program treating filter penetration only, can present the data in the following manner with:

1. The data arranged by filter number, from the lowest to the highest within the particular lot.

2. The data sorted by percent penetration, from the lowest to the highest.

3. Statistical information on the particular lot, including the mean and median penetrations, and the standard deviation.

4. 35mm film graphical plots of the distribution of penetrations displayed on rectilinear, semi-log, normal probability, or log probability plots as desired.

The second retrieval program, utilizing both penetration and pressure drop data can present the information as follows:

1. A tabular listing consisting of filter number, pressure drop, pressure drop corrected to sea level, penetration, the ratio of pressure drop to penetration, and the ratio of the corrected pressure drop to penetration.

2. The above data sorted by either filter number, pressure drop, penetration, or by the ratio of corrected pressure drop to penetration.

3. A statistical analysis of the distribution of pressure drops, penetrations, and ratios of corrected pressure drops and penetrations, including the averages, medians, and standard deviations for each variable.

4. 35mm graphical plots of the distributions of the data in a manner identical to the first retrieval program.

1. Dust Filter Efficiency Results. The results of initial filter efficiency tests on 24 lots of dust filters, totaling approximately 1900 filters, is shown in Table III. The type of media used by each manufacturer is identified by RW for resin-impregnated wool felt media and by R-SW for the resin-impregnated combination synthetic fiber-wool felt media. The letter "M" is used to identify mechanical filters that are not degradable. To insure that the test filters were freshly manufactured and had not inadvertently been damaged during storage and shipment, most of the test lots were purchased directly from the manufacturer, not the distributor. Most of the dust filters are routinely packaged in large lots (50 or 100) without any environmental protection, such as plastic bags.

The range of the sodium chloride aerosol penetration and the average is presented in Table III for each lot of filters tested. The mean penetration and the standard geometric deviation is also listed for several lots of filters tested. The standard deviation is a useful tool in determining manufacturer's quality control. During the next year, an analysis of LASL's initial sodium chloride filter test data will be made to test the applicability of this concept to both dust and fume filters presently on the market.

2. Fume Filter Efficiency Results. Table IV is a tabulation of the initial filter efficiency test results on 12 lots of 743 filters representing four brands of approved fume filters. These are mechanical-type filters, with the exception of the Willson R-11, which is a combination mechanical-resin felt media.

E. Proposed Certification Criteria

Based on our studies and evaluation of dust and fume filters during the past two years, LASL has proposed filter performance criteria for certification of dust and fume

TABLE III

RESULTS OF INITIAL DUST FILTER EFFICIENCY TESTS

Mfr. and Type Dust Filter	Date Rec'd LASL	No. of Filters	Test Rate (lpm)	NaCl Penetration (%)(1) Range	Avg.	Mean	SD
AO R-30 (RW)	5/72	50	16	2.6-11.0	6.0	5.5	-
	9/72	50	16	2.7-6.5	3.8	3.7	0.81
	2/73	100	16	1.2-5.0	3.0	3.0	0.70
	2/73	100	16	1.3-4.8	2.6	2.5	0.70
	2/73	100	16	1.2-4.8	2.8	1.0	0.63
	3/73	100	16	4.6-11.0	7.3	7.4	1.40
Glendale F-10 (RW)	3/73	60	16	0.9-12.0	3.2	3.3	2.54
	3/73	100	16	1.8-18.0	5.3	4.8	2.72
	3/73	100	16	2.4-10.0	4.9	4.6	1.47
MSA "F" (RW)	7/72	40	16	6.0-25.0	14.0	13.0	-
MSA "F" (R-SW)	12/72	97	16	0.3-1.0	0.6	0.5	1.29
	2/73	50	16	0.3-0.7	0.5	0.5	0.07
	5/73	100	16	0.4-1.1	0.7	0.7	0.13
MSA DF-77 (M)	3/73	43	32	0.9-20.0	14.4	15.0	2.02
MSA DF-66 (RW)	9/71	50	32	2.5-55.0	5.3	3.0	-
	7/72	50	32	5.1-13.0	8.0	7.6	-
MSA DF-66 (R-SW)	11/72	50	32	0.6-1.9	1.3	1.2	-
Pulmosan C264 (M)	4/73	100	32	30.0-56.0	42.4	42.0	5.62
Pulmosan C264 (RW)	4/73	100	32	1.0-8.8	3.8	4.0	2.03
Welsh 7500-6 (RW)	4/72	100	16	1.8-4.1	2.8	2.7	-
	1/73	100	16	0.8-2.6	1.4	1.4	0.32
Willson R10 (RW)	5/72	48	16	0.5-2.0	1.0	0.9	0.28
	4/73	100	16	0.3-2.2	0.9	0.9	0.46
	4/73	100	16	0.7-2.3	1.3	1.2	0.3

(RW) Resin-impregnated wool
(R-SW) Resin-impregnated combination synthetic fiber-wool felt
(M) Mechanical filter

** (1)Apparent NaCl penetration, assuming linear response for flame photometer as a function of NaCl aerosol concentration. Recent data indicate that this assumption is not completely correct.*

filters. At a meeting called by NIOSH in April 1973, to consider proposed criteria for certification and amendments to 30 CFR Part 11, LASL proposed the following dust and fume filter certification criteria:

1. A single size standard sodium chloride aerosol be used for testing and certifying both dust and fume filters.

2. Dust filter performance: For mechanical-type (non-degradable) dust filters, a maximum of 5.0% penetration would be permitted; for degradable resin-impregnated filter media, a maximum penetration of 2.0% would be permitted. The maximum of 2% for resin felt takes account of the loss of electrostatic charge during storage.

3. Fume filters: Maximum penetration of 2.0% for mechanical-type filters and 1.0% for degradable-type fume filters is the maximum permitted.

4. It was recommended that the lead fume test for fume respirators be eliminated.

In proposing criteria for a new US dust and fume respirator certification criteria using a sodium chloride aerosol, it was agreed that we should consider any other foreign standards using a sodium chloride aerosol for testing and approval of respirators. The British standards[19,20] for air-purifying particulate respirators and powered air-purifying respirators have been

TABLE IV

RESULTS OF INITIAL FUME FILTER EFFICIENCY TESTS

Test Data by Type Aerosol - All at 16 lpm

Type Filter	No.	PD, 42.5 lpm Range	Avg.	0.3μ DOP, %Pen. Range	Avg.	Mean	6g	0.6 μm NaCl, %Pen.(4) Range	Avg.	Mean	6g
AO R-56(1)	60	25-62	32	0.1-97	4.86	4.80	1.28	0.2-7.6	3.67	3.50	1.27
AO R-56(2)	40	21-34	26	3.0-10.0	6.20	6.0	1.3	2.3-8.2	4.82	4.70	1.40
AO R-56(3)	50	21-27	25	2.2-8.6	4.20	3.9	1.51	3.1-7.6	4.81	4.50	1.29
MSA Type S[1]	94	8-11	9.2	1.15-2.6	1.60	1.62	1.17	0.8-2.5	0.87	1.35	1.19
MSA Type S[1]	27	9-10	9.7	1.2-54	2.10	1.75	1.42	0.9-4.1	1.47	1.47	1.42
MSA Type S[2]	50	8-11	10	0.6-1.8	1.30	1.25	1.20	0.5-2.0	1.25	1.20	1.3
MSA Type S[3]	60	9-10	9.5	1.4-3.0	2.05	1.95	1.26	1.1-2.4	1.71	1.70	1.25
Welsh 7500-7[1]	100			10.0-15.0	11.11	12.6	1.10	2.95-14.0	10.40	8.90	1.19
Welsh 7500-7[2]	48	15-23	17	8.0-18.0	13.72	12.8	1.23	11.0-20.0	16.20	16.1	1.17
Willson R-11[2]	48	11-19	14	0.3-22.0	3.5	1.9	1.8	0.1-14.0	1.90	0.5	1.3
Willson R11[3]	60	10-14	12	0.8-9.0	1.9	1.8	1.37	0.2-4.0	0.71	0.6	1.57

(1) Special Selection from lot by Mfr.
(2) Purchased
(3) From 1 lot for Correlation with Mfr. Pb fume tests
(4) Apparent NaCl penetration, assuming linear response for flame photometer as a function of NaCl aerosol concentration. Recent data indicate that this assumption is not completely correct.

summarized in Table V. Based on our experience during the past several years in evaluating US and British respirators, we believe that the Type B dust respirators are the equivalent to dust and fume respirators approved in the US. They allow a maximum penetration of 5% for a mechanical filter and 3.5% for a resin felt. Based on our studies of degradation, we believe that a maximum of 2.0% should be adopted for resin felt filters. Our studies on the degradation of resin felt filters compared with resin wool batt filters, manufactured in the UK, indicate that the US resin felt filters degrade more rapidly than the English wool batt media. British standards do not recognize a fume respirator--they use only the Type A and Type B dust respirator designation. It is interesting to note that for powered air-purifying respirators the British allow a maximum of 2.0% for any type of resin wool filter.

F. Degradation Study of Resin Felt Filters

In the US, the majority of dust respirator manufacturers have used a resin-impregnated wool felt since the early 1940's. In the UK and Australia, commercial dust respirator filters are commonly made from a resin-impregnated wool batt that is loosely packed and ranges in thickness from 1/2 to 2 inches. Such media also is widely used in Sweden, Norway, Denmark, and Italy. The British have long recognized that resin-impregnated wool batt media will lose its electrostatic charge due to a number of conditions. Dorman[21] has reported that the resin wool batt life is shorter due to the passage of air and, to some extent, dust loading causes loss of efficiency. Also, it suffers from the further drawback of being unable to withstand high concentration of oil mists. Dorman stresses that conditions under which it is used should be rigidly controlled and a limit set to the number of breathing hours before the pad is replaced.

In 1942, Walton[22] reported the results of his comprehensive study of the principles of the resin-treated filter. He indicated that the electrical attraction arises from a film of charged resin particles covering the fibers and adhering to the fibers chiefly by electrical forces. According to Walton, the charges are produced by friction during manufacture of the filter. The impregnated resin particles were said

TABLE V

BRITISH STANDARD METHODS
RESPIRATOR FILTER AND FACEPIECE LEAKAGE TESTS

Type Respirator	Max. initial filter Penetration (1), %	Facepiece Leakage (2) Max. Mean Pen., %
BS 2091:1969		
I. Dust Respirators		
Type A, low resistance, 20 mm	10.0	5.0
Type B		5.0
a. Resin Wool	2.0	
b. Resin Felt	3.5	
c. Mechanical	5.0	
II. Gas Canister, FF	0.25	0.25
III. Gas, Cartridge, 1/2	5.0	5.0
BS 4558:1970 (3)		
Powered Air Purifying,		PP (power on), 0.1
1/2 or FF mask		NP (power off), 5.0
a. High Efficiency		
1. Non-wool	0.10	
2. Resin wool or felt	0.05	
b. Standard Type		
1. Non-wool	5.0	
2. Wool	2.0	

(1) NaCl aerosol, MMD=0.65μm, used for both filter and facepiece leakage test. Filters tested at 30 lpm.

(2) Facepiece leakage test on 10 man test panel, no anthropometric specifications. All subjects must pass. The facepiece is equipped with a high efficiency filter, penetration less than 0.1%.

(3) Filters on powered air purifying respirators tested at 120 lpm.

to have a negative charge and an equal induced positive charge is found on the adjacent regions of the fibers so that the individual fibers and the filter, as a whole, are neutral. Walton claims that the breakdown or degradation of these filters is due to leakage or neutralization of the frictional charges on the resin particles and that the charges are not renewed by the passage of air or particulate matter through the filters. Walton's theories indicate the reason that liquid mists cause the resin-impregnated filters to break down. A liquid which wets the resin or in which the resin is soluble would spread over the surface and discharge the particles. Water will not spread on certain resins and, thus, may be tolerated for a longer period of time.

At the start of this year we initiated an extensive study of the degradation of resin wool felt filter media manufactured in the US. Our studies indicate that high humidity, liquid aerosols or mists and sodium chloride aerosols do progressively neutralize the charge. Apparently, at the point of minimum efficiency, the filter media acts like an ordinary fabric filter. Resin-impregnated wool felt and the combination synthetic wool felt dust filters, approved by B of M, were tested. Results indicate a wide variation in the degradation of filter efficiency loss. The results of our study were reported[23] in a paper entitled, "Degradation of Resin Wool Respirator Filters," at the AIHC in May 1973. This paper will be published in the AIHA Journal; and final results of the study, continuing during the next fiscal year, will be published as a LASL document and a NIOSH document. Some of the information obtained during the past year is summarized in the following discussion.

The degradation of resin-impregnated wool felt and the combination synthetic-wool felt filter media was studied by storing at relative humidities (RH) at 50%, 75%, and approximately 100%, at 72°F. Groups of five filters of each type studied were stored for seven days at the three humidities indicated in a Tenney TH Jr. environmental chamber. Compared to the start of the study, the initial filter penetration was determined and measured at the end of each day during the seven-day storage. The results of this study are shown in Table VI. It is apparent that considerable increase in penetration occurred, particularly at 100% RH. Although the data at 75% relative humidity showed a significant increase over the 50% data, the difference was not nearly as pronounced as between 75% and 100%. We believe that the 75% RH is representative of storage conditions in many parts of the US. We have graphically illustrated the effects of water vapor (75% RH) on the six types of resin felt filters in Figure 13. These data suggest that the increase in penetration is due to the exposure to the humidity and is not linear. These data also suggest that the proposed 2.0% maximum allowable penetration for resin felt filters is realistic.

To study the effect of solvents on the degradation of resin felt filters, we initiated an accelerated test by exposing four types of filters to a concentration of 100,000 ppm of trichloroethane (methyl chloroform) under static conditions for 48 h Sodium chloride filter efficiency tests were run before and after the tests, and the results are shown in Table VII. This preliminary test indicates that methyl chloroform in this concentration will degrade resin felt filter media. We consider these results very preliminary but believe they do indicate further studies should be made with various types of solvents.

V. CRITERIA FOR SELECTION OF A TEST PANEL

One of the most serious objections to the quantitative man test specifications in the Bureau of Mines Schedule 21B was that the respirators were to be tested on "six subjects with widely varying facial shapes and sizes". This requirement was felt to be too vague to be used for evaluating respirators for approval. NIOSH requested that a high priority be placed on development of a test panel which would adequately represent the facial sizes of the male working population. NIOSH contracted with Webb Associates, Yellow Springs, Ohio, to develop the configuration of the test panel with the cooperation of LASL. A conference was held with Webb Associates at which 16 basic facial measurements were proposed.[10]

The first task was to determine if the available military anthropometrical data was representative of the male working population. Facial measurements of approximately 200 Los Alamos men were taken and compared with the military data. It was verified that the military surveys could be used to represent the general working population. From the military data, a 16 subject test panel was developed[24] based on face width (bizygomatic breadth) and face length

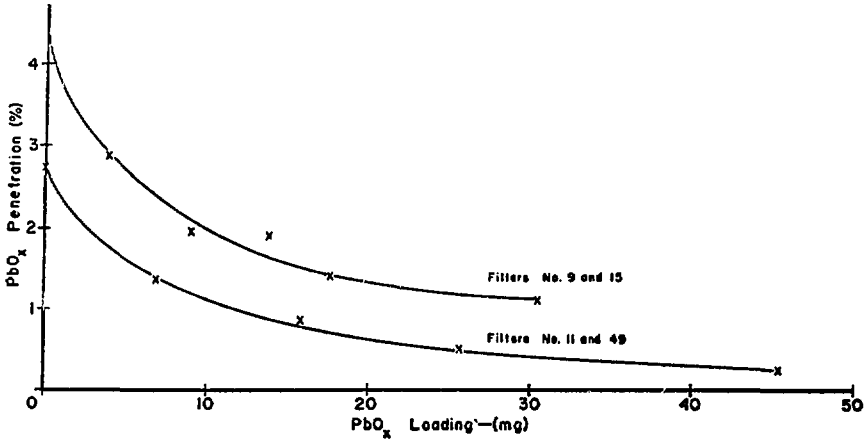
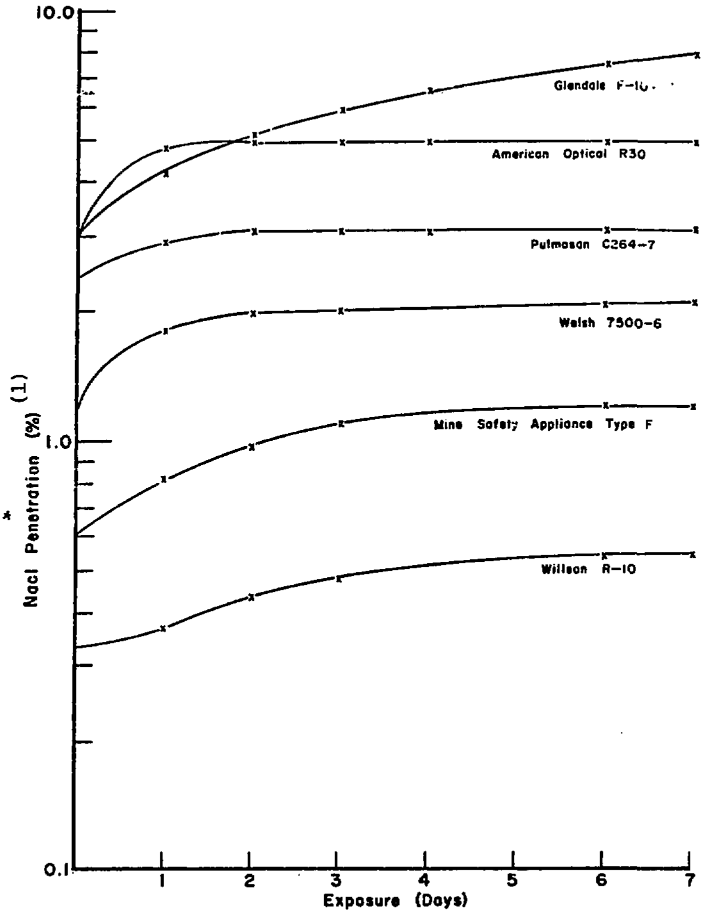


Fig. 12. Lead Fume Tests - AO R56 Respirators



*(I)Apparent NaCl penetration, assuming linear response for flame photometer as a function of NaCl aerosol concentration. Recent data indicate that this assumption is not completely correct.

Fig. 13. Resin Felt Filter Degradation 75% RH at 72 Deg. F.

TABLE VI

RESULTS OF WATER VAPOR DEGRADATION OF SIX TYPES OF RESIN-IMPREGNATED WOOL FELT FILTERS BY STORAGE AT VARIOUS RELATIVE HUMIDITIES

Resin Filter	Relative Humidity (%)	NaCl Penetration, (%)(I) Per Day Storage at Relative Humidity Listed 0	1	2	3	4	5	6	7
AO-R 30	50	2.8	2.8	2.8	2.8	-	-	2.8	3.0
	75	3.1	3.9	3.9	3.9	-	-	3.9	3.9
	100	2.5	3.7	4.5	6.7	7.3	-	7.6	7.7
Glendale F10	50	3.9	5.1	5.4	6.5	6.5	-	6.5	6.5
	75	3.0	4.8	5.1	5.5	-	-	6.9	7.2
	100	3.8	26.5	39.0	57.0	60.0	-	63.0	66.0
MSA-"F"	50	0.90	0.90	1.2	1.2	1.2	-	1.2	1.2
	75	0.62	0.88	0.93	1.1	-	-	1.2	1.2
	100	0.80	1.4	3.4	8.3	9.0	-	9.5	10.2
Pulmosan C-264-7	50	0.53	0.53	0.53	0.53	-	-	0.53	0.53
	75	2.4	2.9	3.1	3.1	3.1	-	3.1	3.1
	100	2.4	4.5	9.4	14.0	17.0	-	20.0	20.0
Welsh 7500-6	50	1.0	1.1	1.2	1.3	1.3	-	1.3	1.4
	75	1.3	1.9	2.0	2.0	-	-	2.1	2.1
	100	1.2	3.1	5.5	9.3	10.0	-	10.5	11.0
Willson R-10	50	0.50	0.50	0.50	0.50	0.50	-	0.50	0.50
	75	0.33	0.35	0.45	0.50	-	-	0.55	0.55
	100	0.38	0.40	0.48	0.75	0.90	-	0.92	1.0

(I)Apparent NaCl penetration, assuming linear response for flame photometer as a function of NaCl aerosol concentration. Recent data indicate that this assumption is not completely correct.

TABLE VII

Effect of Exposure to Methyl Chloroform On Efficiency of Resin-Impregnated Wool Felt Dust Filters

Manufacturer and Type of Filter	No. of Filters Tested	NaCl Penetration, %(2) Initial Avg.	Initial Range	After Exposure Avg.	After Exposure Range
AO R30	5	2.5	2.2 - 3.2	27.2	23.0 - 32.0
Welsh 7500-6	5	1.3	0.9 - 1.8	5.4	4.2 - 6.5
Welsh 7165(1)	5	1.3	1.1 - 1.5	4.0	3.0 - 6.0
MSA Type F (Synthetic Felt)	5	1.6	1.2 - 1.7	27.0	24.0 - 32.0

(I) Single use respirator with resin wool felt filter.
(2) Apparent NaCl penetration, assuming linear response for flame photometer as a function of NaCl aerosol concentration. Recent data indicate that this assumption is not completely correct.

(menton nasal root depression). This panel represented the faces of about 97-98% of the population in terms of length and width based on the mean ±2.5 standard deviations of the two measurements. The limits of this panel were later reduced to ±2.0 standard deviations because of the anticipated difficulty in finding test subjects at the extremes of the panel. It was believed that this modification should not affect the usefulness of the test panel, even though it reduced the coverage to 95% of the population.

This modified panel, with the dimensions based on ±2.0 standard deviations, is shown in Figure 14 with the number of test subjects indicated in each box. The number of subjects in each box is in approximately the

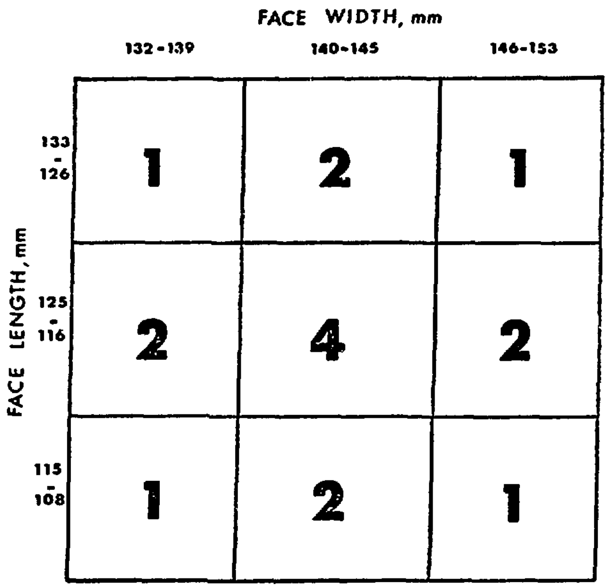


Fig. 14. Modified 16-Man Test Subject Panel

same proportion to the total number on the panel as the percentage of the working population in that box is to the entire working population. In March, 1973, a meeting was held at Los Alamos with Webb Associates to further discuss this project. At that meeting several modifications were proposed for changes to the original panel. It was originally decided that the one panel be used for testing all types of facepieces. At this meeting, it was decided to create an additional panel with dimensions based on lip length and face length for testing half and quarter mask respirators. It was felt that face width has little relationship to the fit of these facepieces whereas lip length, particularly when the wearer smiles or talks, can have a great effect on the seal of the respirator.

Additionally, the number of subjects in the panel was increased to 25. It would be desirable to have as many subjects on the panel as possible. However, as a practical matter, the number had to be reduced to a minimum to limit the number of tests to be run during approval of respirators. Both totals of 16 and 25 subjects were arbitrary. The two 25 subject panels are shown in Figures 15 and 16.

A sequential sampling scheme was also proposed for conducting an approval test. A flow diagram of the plan is shown in Figure 17. A manufacturer would be required to submit five respirators for approval. For the moment, the respirator is assumed to be of a single size which would fit the entire panel. These five respirators would be quantitatively tested on the 25 subjects. If all met a given criteria, the mask would pass at that point. If three or more subjects failed the quantitative man test, the mask would fail. If one or two subjects failed, then the testing would proceed to Step 2 where the subject(s) would be retested on two different masks out of the five submitted. No failures would pass it and one failure would cause the testing to proceed to Step 3 where a new set of subjects of the same size category would be chosen. The number of subjects used would be the same as in the original size category. One failure here would fail the mask.

By this proposed method, the respirator would be given the benefit of the doubt,

FACE LENGTH, mm \ FACE WIDTH, mm	132-139	140-145	146-153
133-126	2	3	2
125-116	3	5	3
115-108	2	3	2

Fig. 15. 25-Man Test Subject Panel For Full Facepieces.

FACE LENGTH, mm \ LIP LENGTH, mm	45-49	50-55	56-60
133-126	2	3	2
125-116	3	5	3
115-108	2	3	2

Fig. 16. 25-Man Test Subject Panel For Half and Quarter Mask Facepieces.

although as the testing proceeds down through the steps, the requirements become stiffer. Step 2 acknowledges the possibility of an anomaly in the particular facepiece, while Step 3 recognizes the potential of an anomalous test subject being included on the panel. Hopefully, over a period of time, the anomalous test subjects would be eliminated from the panel. This method would require a maximum of 34 quantitative man tests to approve a respirator.

Near the end of the year NIOSH asked that female as well as male facial sizes be included on the panel. Also, the question of how to test facepieces which come in more than one size has not been resolved. A formal report covering this work is being prepared and will be completed after the final decisions are made.[25]

VI. QUANTITATIVE MAN TEST METHODS AND DATA

A. Introduction

The highest priority for Project RO 61 was to develop dust and fume respirator-man test equipment and methods (test equipment discussed in Section III). The development and study of quantitative respirator-man test methods must include: 1) pre-test training and fitting, 2) toxicity of test aerosols, 3) exercises performed by subject, and 4) measurement of facepiece leakage only versus total overall leakage with regular dust or fume filter. Some of the variables that affect facepiece leakage measurements include: 1) variations in dust and fume filter efficiency, 2) negative pressure in facepiece, 3) sampling rate from facepiece, 4) per cent leaking aerosol retained in lungs, and 5) exhalation valve leakage. All of these factors and variables are discussed in this section.

Another high priority of Project RO 61 was to perform man tests on test subjects selected by approved anthropometric specifications. Quantitative dust respirator-man tests were made on an anthropometrically selected test panel of 16 men.

A third priority was to assist the NIOSH in developing dust and fume respirator-man test performance criteria for use in future amendments to 30 CFR Part 11, and participate in conferences with the NIOSH, the B of M, and manufacturers. The performance criteria proposed are discussed.

B. Background Information

The results of our studies and development of man-test methods in FY 1971 and 1972 have been reported.[13,14] Man-test methods developed in FY 1971 for half mask respirators equipped with high efficiency filters have been described by Hyatt[26] et al. These DOP aerosol man-test methods measured only facepiece leakage of four types of half mask facepieces used for approved dust and fume respirators. The sodium chloride aerosol man-test methods developed in FY 1972 to measure the overall facepiece leakage of dust and fume respirators equipped with approved filters were reported by Hyatt[27] et al in May 1972. Since the data in this paper illustrates several of the factors and variables affecting overall respirator performance and have not been included in a formal NIOSH progress report, some of the data is included as background information. The paper was reviewed by the NIOSH, B of M, and industry.

1. Affect of Flow Rate and Lung Retention of Aerosol. An increase in the breathing rate of the test subject will increase the flow rate or velocity through the dust or fume filter being tested. In actual use, the breathing rate is directly related to the work rate of the respirator wearer. In our laboratory man tests, the affect of increased flow rate can be illustrated by comparing the penetrations during normal and deep breathing exercises. A comparison of dust and fume respirator-man test leakage during normal and deep breathing is shown in Table VIII. The average penetration during normal and deep breathing is the average for the number of subjects tested. The penetration during these two exercises

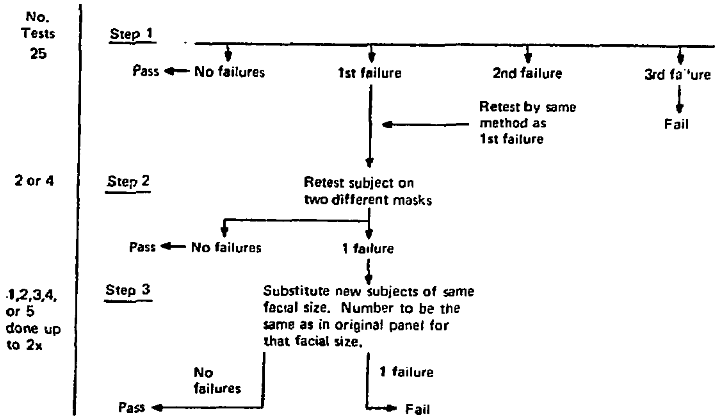


Fig. 17. Sequential Sampling Scheme. 25-Man Panel - 5 Facepieces of One Mask Size.

TABLE VIII

COMPARISON DUST AND FUME RESPIRATOR-MAN TEST
LEAKAGE DURING NORMAL AND DEEP BREATHING

Respirator		Type	No. of	Average NaCl Aerosol Penetration, %		
Iden.	Type	Filter	Subjects	Normal	Deep	% Increase-Deep
AO-R-3030	Dust 1/4	Resin Wool felt	13	5.5	7.5	36
Cesco-90	1/4	"	5	2.7	3.8	41
Glendale GR-4000	1/4	"	10	4.7	7.6	62
Dustfoe 66	1/4	"	14	3.6	4.7	31
Welsh 7100	1/4	"	8	12.3	16.2	37
Willson R-560	1/4	"	12	0.7	1.6	130
Dustfoe 77	1/4	Mechanical	10	5.2	5.4	4
Pulmosan C-264-7	1/4	"	9	7.0	7.2	3
AO-R-6056	Fume 1/2	"	8	5.3	6.2	20
MSA CC-S	1/2	"	8	0.8	1.2	50
Welsh 7507	1/2	Resin Wool felt	8	5.3	7.6	43
Willson 1211	1/2	Mechanical	8	6.1	7.7	26

represents both filter leakage and facepiece leakage. There is a significant difference between the eight types of quarter mask dust respirators tested. However, six dust respirators equipped with resin-impregnated wool felt filters showed a significant increase in penetration during deep breathing, ranging from 31 to 130%. The increase in penetration of the two dust respirators with nonwool mechanical filters shows only a slight increase in penetration during deep breathing.

Data for the four half mask fume respirators were obtained on the same eight test subjects. The increase in penetration for the four fume respirators ranged from 20 to 50%. This data demonstrates that increased flow rate through dust or fume filters resulting from increased breathing rate, is a variable that must be considered when measuring overall dust and fume respirator efficiency.

A significant portion of the test aerosol leaking into the facepiece is retained in the lungs of the test subject. The LASL consultant, Dr. Tom Mercer, estimates that at least 30% of the LASL aerosols breathed by the test subject is retained in the lungs. In measuring the average sodium chloride penetration in the facepiece, the maximum aerosol leakage is not measured. The difference in maximum penetration during inhalation and the minimum penetration during exhalation is illustrated in Figure 18. The minimum penetration during inhalation is shown in the upper peaks and the minimum penetration during exhalation is shown at the bottom of the peaks. Figure 18 is a photograph of part of a recording during a dust respirator-man test. An estimate of the maximum penetration during inhalation only is shown in Table IX. The peak penetration for all of the test subjects was calculated by drawing a line across the peaks recorded during inhalation. The per cent increase calculated from the peaks of the recordings represents an estimate of the maximum leakage during inhalation. If the penetration is sampled only during the inhalation cycle, as previously proposed by Silverman,[28] it can be seen that the average of the maximum penetration peak is much higher than the average LASL used to calculate the overall penetration during the normal and deep breathing exercises. This estimate of the maximum leakage during inhalation only demonstrates that the method of calculating the average leakage overestimates the overall performance of the respirator. A correction factor cannot be calculated from this preliminary data. Additional studies should be made, and this variable must be recognized, when proposing performance criteria. An interim solution is to estimate the maximum exposure based on the peak penetration as recorded during the inhalation cycle.

2. Exercises by Subject. Questions have been raised relative to calculating the overall average penetration by averaging the penetration during each of the various types of exercises performed while the test subject is in the man test chamber. Table X shows the variation in average dust respirator penetration from all exercises and the average penetration calculated without the single maximum penetration.

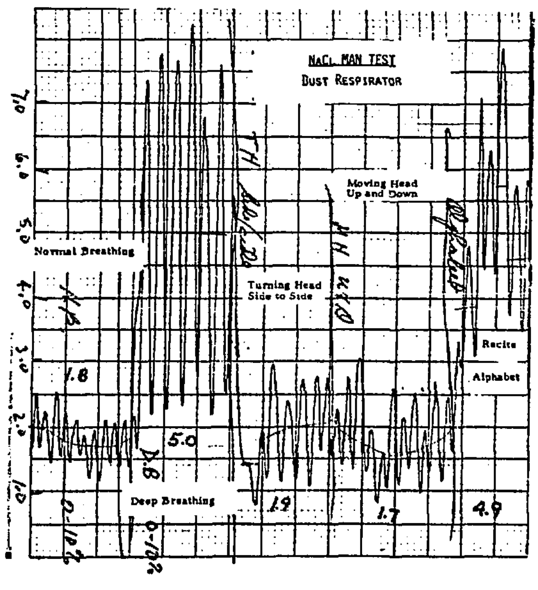


Fig. 18. NaCl Quantitative Man Test.

TABLE IX

COMPARISON AVERAGE PENETRATION DURING
NORMAL AND DEEP BREATHING DURING DUST
RESPIRATOR-MAN TESTS AND PEAK DURING INHALATION

Dust Respirator	No. Man Tests	0.8 NaCl Aerosol Penetration: Normal Breathing Average	0.8 NaCl Aerosol Penetration: Deep Breathing Average	0.8 NaCl Aerosol Penetration: Deep Breathing Peak	% Increase Peak Inhalation
AO R 3030	19	5.5	7.5	10.2	36
Glendale 4000	16	4.7	7.6	10.0	32
Dustfoe 77	19	5.2	5.4	6.9	28

TABLE X

VARIATION IN AVERAGE DUST RESPIRATOR PENETRATION FROM ALL
EXERCISES[1] AND LESS MAXIMUM PENETRATION

Test Subject	Respirator E: Maximum Exercise	Respirator E: Maximum %	Respirator E: Average All	Respirator E: Average -Max.	Respirator F: Maximum Exercise	Respirator F: Maximum %	Respirator F: Average All	Respirator F: Average -Max.
CR 1	S-S	24.0	19.9	19.3	C+A	0.6	0.4	0.3
CR 2	S-S	17.5	12.5	11.8	Smile	4.3	0.9	0.5
LG 1	DB	17.0	13.4	12.9	A+T	0.5	0.3	0.2
LG 2	C	17.0	12.6	11.9	T	1.5	1.0	1.0
LW	Smile	37.0	17.1	14.2	T	1.4	0.8	0.7
TM	Smile	21.0	13.9	12.9	Smile	35.5	6.3	2.7
EH	Smile	34.0	16.3	13.8	Smile	18.5	3.1	1.2
GR	Smile	28.0	19.1	17.8	DB&C	2.3	1.5	1.3
JO	Smile	19.0	14.4	13.7	A	2.4	1.5	1.4

[1]Exercises: NB - Normal breathing, DB - Deep breathing,
S-S - Turn head side to side, C - Cough, Smile and hold,
T - Talking, A - Recite alphabet

Respirators E and F were chosen to illustrate the respirator with the lowest average penetration and the highest average penetration for all test subjects. Both of these respirators are quarter masks and it might be predicted that the maximum penetration would occur during smiling or talking. For Respirator E, five of the seven test subjects did obtain a maximum during the smiling exercises; and for Respirator F, three of the test subjects did obtain a maximum during the smiling, and three during talking or reciting the alphabet. The point being emphasized is that there is only a small difference in the average penetration for Respirator E when it is calculated without the maximum penetration. Two of the test subjects (CR and LG) performed two tests each on the two respirators. They were chosen to illustrate that the maximum penetration occurred for these two test subjects during different exercises. It is realistic to calculate the performance of a respirator by averaging the penetrations during all simulated exercises. However, the results in Table X illustrate that this can vary significantly in some cases due to an exceptionally high maximum leakage.

The method of calculating the penetration during each of the simulated exercises is illustrated in Figure 19. In this case, it can be seen that the maximum leakage occurred during the cough exercises. The cough exercise varies widely between test subjects and is impossible to standardize. It has been dropped from our scheduled exercises. The recording for the penetration during talking is typical and varies widely during the two minute period that the subject reads a standard text. This particular test subject has a very small mouth and insignificant leakage during the smile exercise.

3. Initial Filter Penetration. A comparison of dust respirator-man test results with initial dust filter penetration is shown in Table XI. All of the eight respirators tested were equipped with degradable resin felt filters. This table illustrates the results of man tests on quarter masks and half masks from four different manufacturers. The single filter in the quarter mask and the dual filters in the half mask were the same media and were approved at filter flow rates of 32 and 16 lpm, respectively. This table shows the average filter penetration of six filters from each type respirator at the appropriate flow rates and compares them against the ranges of average aerosol penetration during all exercises performed by various numbers of test subjects. This illustrates that the initial filter penetration is a significant portion of the overall average penetration during all of the man test exercises.

4. NaCl vs. Poly DOP Fume Respirator Man Tests. In the studies to develop suitable man test methods for fume respirators, both a sodium chloride aerosol and a poly DOP aerosol with an MMAD of 1.2 μm were used. This rather large poly DOP aerosol was produced in the LASL prototype poly DOP man test system which did not use an impactor in the generator to break up the larger particles. A comparison of four

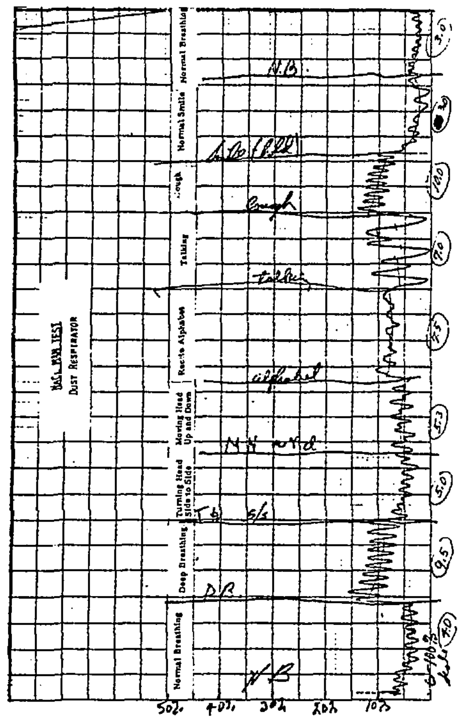


Fig. 19. Method of Calculating Penetrations.

types of fume respirator-man test results using NaCl and poly DOP aerosols is shown in Table XII. The results list both the maximum and average aerosol penetration for both types of aerosol for each subject. The results indicate that the sodium chloride aerosol with an MMAD of 0.6 μm is more penetrating than the large poly DOP aerosol. Results also indicate that the same test subjects cannot always duplicate the smile exercise during man tests on the same respirator run with two different aerosols. This is not due to the type of aerosol used or the test method but is due to the fact that the test subject cannot duplicate the smile exercise from one man test to the next. For example, Subject 7 shows a maximum on smile of 50% with the NaCl and a maximum of 0.5% with DOP for the MSA Custom Comfo fume respirator. If the 50% maximum with NaCl is not used the maximum during talking is only 1.1%, with an average of only 0.6%.

TABLE XI

COMPARISON DUST RESPIRATOR-MAN TEST RESULTS
WITH INITIAL DUST FILTER PENETRATION

Mfr.	Respirator Identification	Respirator Type	Average 0.8 NaCl Aerosol Penetration % — Filter Only[3]-By Flow Rate 16 lpm	Filter Only[3]-By Flow Rate 32 lpm	Man Test Results No. Men Tested	Man Test Results Range-all Tests[4]
AO	R-3030[1]	1/4		5.3	12	5.5 - 9.6
AO	R-6030[2]	1/2	2.6		4	2.5 - 2.9
MSA	Dustfoe 66[1]	1/4		2.7	13	2.8 - 6.4
MSA	Comfo-F[2]	1/2	6.5		4	5.2 - 7.0
Welsh	7100[1]	1/4			7	13.0 - 19.1
Welsh	7506[2]	1/2	6.1		4	4.0 - 11.0
Willson	R-560[1]	1/4		0.3	12	0.7 - 6.3
Willson	1210[2]	1/2	0.4		3	0.4 - 1.8

[1]Single cartridge respirator
[2]Dual cartridge respirator
[3]Average penetration of 6 filters
[4]Average penetration for 9 exercises during man test

5. Toxicity of Aerosols. In developing man test methods, the toxicity of the test aerosol is of major concern. Ideally, a nontoxic aerosol should be used. The sodium chloride aerosol meets this criteria. It is reported[29] that "most normal people ingest 5 to 20 grams of sodium chloride per day". It is worth noting that the water-sodium chloride balance is important in human metabolic considerations; witness shipwreck survivors who perish not because of too much NaCl, but because of a water-NaCl imbalance. The quantity of sodium chloride inhaled during a man test with poor fitting quarter mask dust respirators is insignificant compared to the quantity ingested daily.

There has always been a concern about the toxicity of the DOP aerosol for man tests, especially the thermally-generated DOP aerosol. From the beginning of DOP man tests any man test was terminated when the leakage was greater than 1% for both full face and half mask respirators. The DOP is normally a clear liquid, but will turn an amber color within 8 hours when thermally generating DOP aerosols. The odor of the decomposition products is detected during facepiece leakage tests and is disagreeable to the majority of the subjects. Because of this, thermally-generated DOP man test system was eliminated in January, 1973.

The air-generated poly DOP does not decompose and has no disagreeable odor. The TLV of 5.0 mg/m^3 indicates a low toxicity.[30] During a man test with air-generated poly DOP, the test subject's weighted daily exposure is estimated to be less than 1% of the TLV. This is especially true if the test is terminated when the maximum penetration exceeds 2.0%.

6. Effect of Facial Hair. The results of the studies on the effect of facial hair on respirator performance has been reported.[31] Test results using a sodium chloride aerosol showed that the effect of facial hair on the performance of a respirator

TABLE XII

COMPARISON FUME RESPIRATOR-MAN TEST RESULTS WITH NaCl[1] AND POLY DOP[2] AEROSOLS BY TEST SUBJECT

Test Subject Number	Test Aerosol	Maximum and Average Aerosol Penetration %							
		AO R-6056		MSA-CC-S		Welsh 7507		Willson 1211	
		Max.	Av.	Max.	Av.	Max.	Av.	Max.	Av.
1	NaCl	6.0	4.6	1.3	0.7	7.1	5.2	8.5	7.3
	DOP	3.6	3.5	0.4	0.3	3.6	3.3	8.0	5.1
2	NaCl	9.0	7.0	1.7	1.2	7.8	5.8	19.0-UD	10.0
	DOP	3.4	3.4	1.0	0.5	3.6	3.3	3.6	2.9
3	NaCl	7.5	5.8	1.9	1.4	6.9	5.5	15.5-S	6.9
	DOP	3.3	3.1	1.0	0.4	3.0	2.9	14.0-S	5.0
4	NaCl	7.3	6.0	0.8	0.6	6.5	4.9	22.0-S	11.7
	DOP	3.6	3.4	15.0-S	2.2	20.0-S	5.3	38.0-S	8.4
5	NaCl	5.7	5.5	1.4	1.0	8.5	6.4	25.0-S	10.7
	DOP	3.4	3.3	0.9	0.6	3.4	3.2	26.0-S	13.9
6	NaCl	12.0-S	10.3	20.0-S	3.2	40.0-S	9.9	6.1-C	3.0
	DOP	9.2	4.3	30.0-S	3.7	4.0	3.5	2.9-C	2.7
7	NaCl	8.0-S	5.0	50.0-S	6.8	5.5	4.3	32.0-S	8.0
	DOP	18.0-C S	13.0	0.5	0.4	3.6	3.3	13.0-S	4.0
8	NaCl	3.6	3.2	2.1-S	1.0	17.0-S	7.0	63.0-S	12.2
	DOP	33.0-S	9.3	3.0-S	0.8	29.0-S	6.3	34.0-S	13.1

1. NaCl Aerosol, MMAD = 0.6 μm.
2. Polydisperse DOP Aerosol, MMAD = 1.2 μm.

NOTE: Only where a significant difference between the average and maximum penetration occurred , the exercise causing the high penetration was noted.

UD - Moving head up and down.
S - Smile
C - Cough

depends upon the degree to which the hair interferes with the sealing surface of the respirator, the physical characteristics of the facial hair, the type respirator worn in relation to the subject's facial characteristics, and other factors. It was concluded that persons with excessive facial hair, such as facial stubble, sideburns and beards which interfere with the respirator seal cannot expect to obtain as high a degree of respirator performance as persons who are clean shaven.

C. Man Test Results on 16-Man Panel

As a means of evaluating the proposed concept of an anthropometrically selected test panel and man test procedures, quantitative man tests were run on many of the approved single use, quarter mask, and half mask dust respirators on the market. These tests were run on a 16-man test panel selected from readily available subjects at Los Alamos. The subject selection was made on the basis of face length and width and the panel limits based on ±2.0 standard deviations of the military mean dimensions. Figure 20 shows the location of the 16 subjects on the test panel.

The respirators were tested by two basic methods. One method was to measure the overall performance or efficiency of the respirator by equipping the facepiece with the normal approved dust filter, and measuring the penetration with a sodium chloride aerosol having an MMAD of 0.6 μm. The sodium chloride aerosol was produced

± 2 SD L 108-133 W 132-153

FACE LENGTH \ FACE WIDTH	132 133	134 135	136 137	138 139	140 141	142 143	144 145	146 147	148 149	150 151	152 153
133 132											
131 130				GT GT							
129 128						ARM					
127 126							JA			JP	
125 124						AH					
123 122		AL			KC						
121 120			TM			JO		LG RM			
119 118											
117 116					OB						
115 114				CR							
113 112					JD					WS	
111 110											
109 108							MT				

Fig. 20. Location of 16 Test Subjects Used for Man Tests on Dust Respirators.

by the LASL Model I NaCl aerosol system. The second method was to measure only the facepiece leakage. This was done by replacing the dust filter with a high efficiency filter (s), and the man tests were run with the 0.8 μm MMAD polydisperse DOP aerosol produced by the LASL Model A polydisperse DOP aerosol system.

The data were analyzed in two ways, based on the exercises performed. The first method determined the average penetration while the subject performed the seven exercises of normal breathing, deep breathing, turning the head from side to side, moving the head up and down, talking, normal smiling and coughing. The second method of calculating the average penetration was to exclude the smile and cough and is referred to as the basic five exercises. The reason for using these two methods is that there was still some question as to whether smile and cough should be included in the exercises designed to simulate work conditions. Facepiece leakage during normal smiling and talking is indicative of the relationship between lip length and the width of the facepiece. However, a smile is a difficult exercise to duplicate. Also, a smile is a facial expression and all facial expressions are difficult to duplicate between test subjects and, therefore, should not be used as a standard exercise for meeting performance criteria to evaluate respirators for certification. A cough will determine the stability of the mask on the face and also the performance of the exhalation valve. However, it is also difficult to duplicate; therefore, it should not be included in the exercises for standard performance criteria testing.

1. Measurement of Overall Respirator Performance. The results of measurement of overall respirator performance on 14 types of dust respirators is shown in Table XIII. Where the respirators were equipped with replaceable filters, the sodium chloride penetration of these filters was determined before each test. A new set of filters was used for each test. The range of the initial filter penetration for each single or set of filters used is shown in the left-hand columns along with the average for each type of filter tested.

The overall penetration, as summarized in this Table, was a combination of leakage around the sealing surface of the facepiece and leakage through the filter. Theoretically, if the filter leakage were subtracted from the overall leakage, then the leakage due to the facepiece alone could be estimated. However, for the MSA and AO half mask respirators and with the Welsh quarter mask, this argument breaks down as the average filter penetration was greater than the overall average penetration during the quantitative man tests. Obviously, this is impossible. It is suspected that this may be due to the differences in filtration efficiency under the steady flow conditions of the filter test as contrasted to the cyclic flow conditions of the man tests. The Aerosol Section at LASL is investigating this phenomena.

A comparison of the average panel penetration for all seven exercises with that for the five basic exercises indicates that the average of the five basic exercises is lower, but varies considerably from respirator to respirator. For example, the Pulmosan 264-7 respirator shows that the panel average for the five basic exercises is 5% lower, while that for the MSA Dustfoe 66 is only 0.8% lower. Also, the four half mask facepieces show a smaller difference than do the quarter mask dust respirators. There is no significant difference in the three single use respirators.

LASL has proposed an overall performance criteria for dust respirators equipped with the approved filter and using a sodium chloride aerosol for man tests. The average penetration shall not exceed 5% and the maximum penetration shall not exceed 10%. In the right-hand column of Table XIII, the number of men that failed the proposed performance criteria while performing the five basic exercises proposed for the performance criteria test is indicated. Of the quarter mask dust respirators with complete tests on the 16-man panel, it can be seen that only the Willson 560 respirator with three failures and the Welsh 7506 half mask with one failure can even be considered for further testing, based on the proposed testing scheme discussed in Section V. All of the other dust respirators would be failed without further testing.

2. Measurement of Facepiece Leakage Only. The results of quantitative polydisperse DOP man test results on eight dust respirators equipped with high efficiency filters are shown in Table XIV. The same 16-man test panel discussed above was used for these tests. The penetrations shown are essentially due to facepiece leakage only since all filters showed a penetration of less than 0.03%.

The exhalation valve leakage for the half mask respirators is less than 0.05%. This is based on man tests when the respirator was equipped with a high efficiency filter and leakages less than 0.01% were obtained. Based on dynamic leakage tests of the same types of exhalation valves, Burgess[32] reported leakages ranging from 0.005 to 0.07%. The tests were made with new clean valves. The original exhalation valve on the MSA Dustfoe 66 would occasionally show high leakages (5-20%) when the valve stuck under the seat. This was corrected by MSA in the fall of 1972, and man

TABLE XIII

Comparison NaCl[1] Man Test Results on Test Panel[2] Wearing Dust Resp.rators Equipped with Approved Dust Filter: Measure of Overall Performance

Respirator		Initial Filter Pen., %		All 7 Exercises Av. Pen., %		5 Basic Exercises[3] Av. Pen., %		No. Failing Proposed Performance[4] Criteria
Identification	Type	Range	Av.	Panel Range	Panel Av.	Panel Range	Panel Av.	
MSA Dustfoe 66	1/4	2.5-6.0	3.4	2.9-11.0	6.3	2.5-9.0	5.5	9
MSA Dustfoe 77	1/4	1.7-3.0	2.5	4.0-31.0	11.1	4.0-26.0	8.5	11
AO 3030	1/4	2.7-12.0	5.2	6.6-19.0	11.9	6.6-15.0	10.5	16
AO 2090	1/4	1.0-8.5	4.6	4.0-30.0	13.5	4.0-28.0	12.3	13
Willson 560	1/4	0.1-1.9	0.43	0.5-21.0	4.5	0.5-21.0	3.2	3
Pulmosan C264-7	1/4	3.8-10.2	8.0	4.8-23.0	13.7	3.0-16.0	8.7	14
Welsh 7100	1/4	4.1-6.8	5.2	1.4-18.	5.3	1.6-13.8	4.4	1/11
3M 8710	SU			6.0-16.9	12.5	6.0-17.4	12.5	16
AO Dust Demon	SU			11.4-27.6	14.5	11.2-22.4	14.4	16
Welsh 7165	SU			2.7-12.0	5.7	1.3-9.0	4.8	7
AO 6030	1/2	3.1-12.5	6.8	2.0-21.0	4.9	2.0-14.0	4.7	4
Glendale 2010	1/2	0.8-2.3	1.5	1.7-21.0	6.1	1.6-21.0	5.7	7
MSA-CC-F	1/2	6-25	4.0	3.7-16.9	7.8	4.1-16.4	8.1	11
Welsh 7506	1/2	0.9-3.5	1.6	1.1-5.3	2.6	1.3-5.6	2.5	1

(1) NaCl Aerosol, MMAD = 0.6 ± 0.1 μm.

(2) Anthropometrically selected 16 man test panel representing 95% of U. S. male face sizes.

(3) 5 Basic exercises excludes smile and cough.

(4) Standard Respirator: Allowable Penetration, maximum = 10.0%, average = 5.0%.

SU Single Use.

tests were made on the Dustfoe 66 with the improved valve, and it was possible to obtain leakages less than 0.1%.

A comparison of the average penetration from all seven exerci--s and from the five basic exercises indi. :es a significant difference for the five quarter mask dust respirators and for the MSA Custom Comfo. The Welso 7507 respirator, which is approximately one-half inch wider than any of the respirators tested, shows no difference.

For respirators equipped with a high efficiency filter, LASL has proposed the following performance criteria: A maximum leakage during any of the five basic exercises of 5% and a maximum average leakage of 2.5%. In the right-hand column of Table XIV, the number of men on the 16-man panel failing the proposed performance criteria is listed. The results indicate that none of the eight respirators will pass the proposed performance criteria. This proposed criteria allows for a maximum facepiece leakage of 5% and a maximum leakage of 5% for the filter. This is equivalent to a maximum overall leakage of 10%. This system more realistically evaluates the size of the respirator on an anthropometrically selected test panel because it measures only facepiece leakage. For example, the American Optical 6057 respirator, which is approximately one-half-inch longer than the medium-sized respirators, such as the MSA Custom Comfo and the Welsh 7508, shows four failures while the latter two show only one each.

TABLE XIV

Comparison DOP[1] Man Test Results on Test Panel[2] Wearing Dust Respirators Equipped With High Efficiency Filters to Measure Facepiece Leakage

Type Respirator with High Efficiency Filter	Av. Pen., %-All Exer.[3]			Av. Pen., %-5 Basic Exer.[4]			Number on Panel Failing Proposed Criteria[5]
	Panel Range	Panel Av.	Panel No.>5%	Panel Range	Panel Av.	Panel No.>5%	
MSA Dustfoe 66	0.4-13.6	4.3	5	0.1-3.1	1.3	0	3
MSA Dustfoe 77	0.15-13.1	3.2	3	0.2-11.8	1.9	1	3
AO 3030	<0.01-14.7	4.5	3	<0.01-5.5	1.7	2	4
AO 2090	<0.01-14.6	3.3	3	<0.01-3.0	1.1	0	2
Willson 560	0.05-11.0	4.5	7	0.05-9.6	1.8	1	4
AO 6030	0.02-3.1	1.3	0	0.02-3.0	1.0	0	4
MSA Custom Comfo	<0.01-9.0	2.5	3	<0.01-3.4	0.5	0	1
Welsh 7506	<0.01-4.0	0.3	0	<0.01-4.0	0.3	0	1

1. Polydisperse DOP, MMAD = 0.8 μm.
2. Anthropometrically selected 16 man test panel representing 95% of U. S. male face sizes
3. Seven exercises includes smile.
4. Five basic exercises excludes smile and cough.
5. Facepiece leakage only and five basic exercises: Allowable penetration, maximum=5.0%, average=2.5%.

The results are realistic because no one has predicted that one size of respirator would fit a panel representing 95% of the adult male population. Results indicate that none of them passed the proposed criteria and that at least two sizes of respirators are necessary for all eight types to pass.

For a comparison with British Standard (BS) 2091[19] (see Table V), the number of panel members with an average penetration greater than 5% is listed in Table XIV. The BS 2091 standard allows a maximum leakage not to exceed a mean value of 5% on ten test subjects wearing a respirator equipped with a high efficiency filter and, therefore, measures only facepiece leakage. However, no facial movements of any type are permitted in the BS 2091 man test procedure. Since the five basic exercises include talking, a direct comparison with the British Standard cannot be made. However, Table XIV shows that none of the 16-man panel testing the three half masks had an average penetration exceeding 5%, and two of the five quarter mask dust respirators equipped with high efficiency filters did not exceed the maximum penetration of 5%. The other three would have failed the British test criteria.

D. Data Retrieval

At the end of FY 1973 approximately 4000 quantitative man tests of all types had been run on air purifying respirators and self-contained breathing apparatus. Each one of these tests has over 20 variables. This mass of information has made it almost impossible to statistically treat these data by hand calculations. Starting late in the year, computer programs for the entry and retrieval of quantitative man test data were developed, and the tests entered on punch cards. This time consuming, but necessary, program has consumed about five man-months and is not yet complete. Yet to be done is a general clean up of the programs and correction or deletion of questionable data. After working with the preliminary print outs, some further modification of the computer programs is likely to be required to present the data in a more usable form.

As presently structured, the program stores all of the data from the man test, including test number, date, operator, subject, mask manufacturer, mask type, etc. It then can compute the following four average penetrations:

a. Average of the five basic exercises, normal breathing, deep breathing, turning head side to side, moving head up and down, and talking.

b. Average of the five basic exercises, plus normal smile.

c. Average of the five basic exercises, plus a final normal breathing at the end of the test.

d. Average of the five basic exercises, plus smiling, plus a final normal breathing at the end of the test.

The program then sorts the tests from the lowest to the highest penetration values of whichever of the variables is chosen. By specifying a particular mask type, test aerosol, etc., the program will automatically eliminate from the print out all tests which do not satisfy the conditions.

Once all of the anomalies are removed from the data bank, and the program is modified to our satisfaction, we should be able to quickly and accurately provide statistical comparisons of quantitative man test data.

VII. REVIEW OF MANUFACTURERS' QUALITY CONTROL PLANS

NIOSH requested that LASL review the quality control plans for respirators submitted for approval under 30 CFR Part 11.[12] Comments were requested only upon those parts which pertain to testing of components to assure that they will meet the requirements of 30 CFR Part 11. Table XV is a listing of items received from NIOSH for comment or information and the action taken by LASL.

The review of the quality control plans for the MSA Comfo and Comfo II respirators were the most involved, as they included the two respirator facepieces and seven types of cartridges. Because the criteria for preparation of quality control plans had not been firmly established by NIOSH, meetings were held in Cincinnati in August, 1972, to discuss the plans being submitted.

VIII. RECOMMENDING RESPIRATORS FOR NIOSH CRITERIA DOCUMENTS

Recommendations of respirators for NIOSH Criteria Documents were made as requested. Also, a proposed respirator selection guide was prepared and distributed to appropriate agencies and manufacturers for comments. The first selection guide (Table XVI) received many comments, and from these Table XVII was prepared.

Table XVI differs from Table XVII in several ways, a major one being the different protection factors (PF's) for various types of devices. The selection guide of 10X time-weighted average (TWA) for both half and quarter facepiece dust and fume respirators is based on new quantitative man tests on dust respirator facepieces equipped with high efficiency filters. This permits the measurement of facepiece leakage only, on both quarter and half facepieces. The data indicated both types will pass the criteria for a protection factor of 10, based on facepiece leakage only. Other changes in Table XVII are explained in the footnotes to the table.

Table XVII has been reviewed by several people and the following general comments were agreed upon, at least as a general principle.

1. A Selection Guide for respirators for non-emergency or routine use should be considered separately from self-contained breathing apparatus (SCBA) for emergency use.

2. A PF of 5 for valveless single use respirators, and 10 for the single use type with exhalation valve, is proposed as

TABLE XV

STATUS SUMMARY

REVIEW OF MANUFACTURERS' QUALITY CONTROL PLANS

FY 1973

Manufacturer	Information on File	Action Taken
AGA Corp.	"Blind" letter from NIOSH to company, 8/16/72	None
Glendale Optical	Quality Control Manual	Comments prepared. No action taken by NIOSH request. NIOSH will advise.
Mine Safety Appliances Co.	Quality Control Manuals for Comfo and Comfo II respirators.	Review complete. Two sets of comments prepared and forwarded to NIOSH. Meetings held with NIOSH and MSA representatives.
3M Co.	Quality Control Manual for 8710 respirator.	Review complete and comments forwarded to NIOSH.
Personal Environment Systems, Inc.	"Blind" letter from NIOSH to company, 6/20/72.	None (PES now has been purchased by the 3M Co.)
U.S. Divers	"Blind" letter from NIOSH to company, 6/26/72.	None
Welsh Man. Co.	"Blind" letter from NIOSH to company. Quality Control Manual has been returned to NIOSH.	Review complete and comments forwarded to NIOSH, 8/15/72.
Biomarine Ind., Inc.	"Blind" letter from NIOSH to company, 8/16/72.	None

an interim guide for currently available approved devices.

3. Considering that powered air-purifying respirators with dust and fume filters have not been approved, a PF of X should be assigned. A PF could be assigned after an applicable particulate filter has been tested for a specific contaminant.

4. After considering the statistical variations in the PF's of seven facepieces currently in use for SCBA operated in the demand mode (negative facepiece pressure), a compromise is proposed. For routine use, a PF of 100; for emergency use by highly trained men, a PF of 200.

5. The terms "selection guide" and/or "maximum use concentration," may be preferable to PF.

6. The PF's in Table XVII for types of respirators other than those noted in items 2, 3, and 4 above, in general, are acceptable.

A new table was developed from the above and reported in a paper by Hyatt.[33] The proposed Respirator Selection Guide for Protection Against Airborne Particulates (Table XVIII) was approved by the AIHA-ACGIH Respirator Committee. The footnotes were not approved, pending further study.

The following criteria documents were reviewed and respirators recommended for:

Cadmium	Coke oven emissions
Benzene	Silica dust
Toluene	Lead
Trichloroethylene	Beryllium
Mercury	Carbon monoxide
Sulfur dioxide	Fiber glass
Toluene diisocyanate	Chromic acid
	Sulfuric acid mist
	Arsenic

TABLE XVI

RESPIRATOR SELECTION GUIDE FOR PROTECTION AGAINST AIRBORN PARTICULATES FOR NIOSH CRITERIA DOCUMENTS

Type Respirator, Filter, Facepiece	Filter Efficiency, %		Protection Factor
	NaCl	DOP	
Air Purifying Respirators			
Single Use, "Dust", 1/4 or 1/2	75-90	70-80	5
Air-purifying, "Dust", 1/4 facepiece	75-95	--	5
Air-purifying, "Dust", 1/2 facepiece	75-95	--	10
Air-purifying, "Fume", 1/4 facepiece	95-99	90-98	5
Air-purifying, "Fume", 1/2 facepiece	95-99	90-98	10
Air-purifying, "Hi-Eff.",1/4 facepiece	99.98+	99.97+	5
Air-purifying, "Hi-Eff.",1/2 facepiece	99.98+	99.97+	10
Air-purifying, "Hi-Eff.",FF facepiece	99.98+	99.97+	100
Powered Air-purifying, with "Dust" Filter, 1/2	75-95	--	10
Powered Air-purifying, with "Fume" Filter, 1/2	95-99	90-98	20
Powered Air-purifying, with "Hi-Eff.", 1/2	99.98+	99.97+	500
Powered Air-purifying, with "Hi-Eff. Eff.", FF	99.98+	99.97+	1000
Powered Air-purifying with "Hi-Eff." Hood	99.98+	99.97+	1000
Atmosphere-Supplying Respirators			
Supplied Air - Demand - 1/2	--	--	20
Supplied Air - Demand - FF	--	--	200
Supplied Air - P-D in PP mode, 1/2	--	--	5000
Supplied Air - P-D in PP mode, FF	--	--	10000
Supplied Air - Continuous flow, 1/2	--	--	5000
Supplied Air - Continuous flow, FF	--	--	10000
Supplied Air - Continuous flow, Hood	--	--	10000
Supplied Air - Continuous flow, Suit	--	--	10000
SCBA-Air-Open Circuit, Demand, FF	--	--	200
SCBA-Air-Open Circuit, Positive Pressure, FF	--	--	10000
SCBA-Air-Open Circuit, P-D, PP mode, FF	--	--	10000

Combination Respirator

Any combination of air-purifying and atmosphere supplying respirator.	Protection factor for type and mode of operation as listed above.

TABLE XVII

RESPIRATOR SELECTION GUIDE[1] FOR PROTECTION AGAINST AIRBORNE CONTAMINANTS[2]
FOR NIOSH CRITERIA DOCUMENTS

Type Respirator, Filter[3], Facepiece[4]	Selection Guide[5] Multiples of TWA for 8 hr. day,
Air Purifying Respirators	
Single Use,[6] Dust[7]	5
Air-purifying, Dust, 1/4 or 1/2 facepiece	10
Air-purifying, Fume,[8] 1/4 or 1/2 facepiece	10
Air-purifying, Hi-Eff.[9], 1/2 facepiece	10
Air-purifying, Hi-Eff., FF facepiece	100
Powered Air-purifying, with Applicable Particulate Removing Filter	200
Powered Air-purifying, with Hi-Eff. Filter, Hood or Facepiece	1000
Atmosphere-Supplying Respirators	
Supplied Air-Demand - 1/2	10
Supplied Air-Demand - FF	100
Supplied Air-P-D in PP mode, 1/2[10]	1000
Supplied Air-P-D in PP mode, FF[11]	2000
Supplied Air-Continuous flow, 1/2[10]	1000
Supplied Air-Continuous flow, FF[11]	2000
Supplied Air-Continuous flow, Hood[12]	2000
Supplied Air-Continuous flow, Suit[13]	2000
SCBA-Air-Open Circuit, Demand, FF	100
SCBA-Air-Open Circuit, Positive Pressure, FF[14]	10000+
SCBA-Air-Open Circuit, P-D, PP mode, FF[14]	10000+
Combination Respirator	
Any combination of air-purifying and atmosphere supplying respirator.	Selection Guide for type and mode of operation as listed above.

FOOTNOTES FOR RESPIRATOR SELECTION TABLE XVII

1. The Selection Guide is proposed for use in the preparation of recommended respirators for specific NIOSH Criteria Document. An illustration of its current use is in proposed criteria documents for silica dust, fibrous glass, sulfur dioxide, benzene, sulfuric acid mist, etc. Final criteria documents for asbestos, beryllium, CO, and PB contain errors and/or have contradicting statements relative to protection provided.

2. Contaminants include gases, vapors, dusts, fumes, and mists. Each type of specific contaminant would have to be considered as to the size if it is a dust, fume, or mist, and the sorbant if a gas or vapor. Example: sulfuric acid mist criteria—concentrated sulfuric acid mist gives off SO_3 which is very fine and requires a high efficiency filter. It is known that dust filters are satisfactory for dilute sulfuric acid mist.

3. The filter may be either a dust or chemical filter or a combination. Where B of M approvals exist, such as chemical cartridge respirator for organic vapors, SO_2, etc, they should be specified. Where approvals do not exist it is suggested that specific sorbents be specified. Example: Iodized charcoal for mercury vapor.

4. Tests made at LASL during the past five months indicate that when considering facepiece leakage only, there is no significant difference between 1/4 mask and a 1/2 mask. Based on facepiece leakage only, where 1/4 and 1/2 facepieces fitted with high efficiency filters have been tested on a 16-man panel representative of 95% of U. S. male face sizes, they all meet the requirements for protection up to 10X TLV.

5. The term "Selection Guide" has replaced "Protection Factor" as originally proposed in September, 1972. This suggested change is to emphasize that their main purpose is for selection of a given type of device when the concentration is known or projected to be a certain level. It is recognized that they are the equivalent of a protection factor. I wish to recognize that several individuals have reviewed my September, 1972, proposed selection guide and made valuable recommendations. They are R. Schutz, E. Kloos, A Gudeman, and W. Burgess. Many of the changes made reflect their recommendations; however, I wish to emphasize that the numbers given in no way constitute unanimous approval of this group.

6. A single use or disposable respirator with valves approved under Schedule 21B is approved for silica dust, asbestos, etc. and dusts with a TLV >0.1 mg/m^3, including but not limited to lead, cadmium, etc. A single use valveless approved under Part 11 (21C) excludes toxic dusts. Respirator-man tests and filter tests made at LASL show overall respirator efficiency on the 3 currently approved, single use respirators ranging from 70 to 90%. Therefore, it is recommended that they only be recommended for protection up to 5X TLV of silica dust, asbestos, etc. and exclude their use for toxic dusts such as lead, Cd, etc.

7. Dust filter in this table refers to a dust respirator approved by the silica dust test, and includes all type of media, that is, both non-degradable mechanical type media and degradable resin-impregnated wool felt media.

8. Fume filter in this table refers to a fume respirator approved by the lead fume test.

9. High efficiency filter in this table refers to a high efficiency particulate respirator. The filter must be at least 99.97% efficient against 0.3 μm DOP to be approved.

10. A positive pressure supplied air respirator equipped with a 1/2 mask facepiece does not provide eye protection. Thus, it is proposed that the Selection Guide should be 1/2 that of the similar device equipped with a full face mask.

11. A positive pressure supplied air respirator equipped with full facepiece provides eye protection but is not approved for use in atmospheres immediately dangerous to life. It is recognized that the facepiece leakage when a positive pressure is maintained should be the same as a SCBA operated in the positive pressure mode. However, to emphasize that it basically is not for emergency use, the Selection Guide is limited to 2,000.

12. The design of the supplied air hood (with a minimum of 6 cfm of air) may determine its overall efficiency and protection. For example, when working with the arms over the head, some hoods draw contaminate into the hood breathing zone. This may be overcome by wearing a short hood under a coat or overalls. Other limitations specified by the approval agency must be considered before using in certain types of atmospheres.

13. Design of suit may limit protection factor.

14. The SCBA operated in the positive pressure mode has been tested on a selected 16-man panel and the facepiece leakage recorded as <0.01% penetration, therefore, I have suggested 10,000+ because at this time the lower limit of detection does not warrant listing a higher number. Several of the proposed criteria documents simply recommend a positive pressure SCBA for any concentration greater than a specified concentration. I believe this is consistent with the 10,000+ that is proposed. We must have an emergency device for use in unknown and unlimited concentration. However, other limitations such as skin absorption of HCN or tritium must be considered.

TABLE XVIII

RESPIRATOR MAXIMUM USE CONCENTRATION SELECTION GUIDE FOR PROTECTION AGAINST AIRBORNE PARTICULATES

Type Respirator (For Non-emergency Use)	Facepiece Pressure	Maximum Use Concentration Selection Guide Multiples of TWA and Ceiling
Air Purifying, Filter Facepiece		
Single Use, Dust, Valveless	-	5
Single Use, Dust, With Valve	-	10
Dust, 1/4 or 1/2	-	10
Fume, 1/4 or 1/2	-	10
Hi-Eff., 1/2	-	10
Hi-Eff., FF	-	100
Powered Hi-Eff., 1/2, FF, or Hood	+	1000
Powered, Dust or Fume, All	+	X
Supplied Air, Mode, Facepiece		
Demand - 1/2	-	10
Demand - FF	-	100
P-D in PP Mode, 1/2	+	1000
P-D in PP Mode, FF	+	2000
Continuous Flow, 1/2	+	1000
Continuous Flow, FF	+	2000
Continuous Flow, Hood	+	2000
Continuous Flow, Suit	+	2000

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