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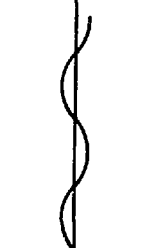

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SELECTION OF RESPIRATOR TEST PANELS REPRESENTATIVE OF U.S. ADULT FACIAL SIZES

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ABSTRACT

As requested by the National Institute for Occupational Safety and Health (NIOSH), the Los Alamos Scientific Laboratory Respirator Research and Development Section, Industrial Hygiene Group, has prepared anthropometric specifications for subjects to test the fit of half-mask, quarter-mask, and full-facepiece respirators. A facial survey of 200 males was conducted, with results similar to those of a recent survey of some 4000 U.S. airmen. Subjects were selected on the basis of face length and face width to wear full-face masks in tests. For testing half- and quarter-masks, face length and lip length were used. Test panels containing 25 male-and-female subjects were used to represent a majority of the working population. A sequential sampling scheme was developed to reduce the amount of testing required to determine if a mask provides adequate protection for different facial sizes. Examples of man test results are given.

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1. INTRODUCTION AND SUMMARY

Respirators submitted by industry to the Government for testing and approval must meet the requirements of *Title 30, Code of Federal Regulations, Part 11* (30 CFR 11).[1]

To satisfy the requirements of 30 CFR 11, each type of respirator must be tested with men actually wearing the device, but specifications for the test subjects have been very general. For example, in testing self-contained breathing apparatus (SCBA), six persons are to wear the device in a test atmosphere. Gas masks are to be tested by "... persons having varying facial shapes and sizes." Dust, mist, and fume respirators "... shall be designed and constructed to fit persons with various facial shapes and sizes either: (1) by providing more than one facepiece size, or (2) by providing one facepiece size which will fit varying facial shapes and sizes."

The Respirator Research and Development Section, LASL, was asked by the National Institute for Occupational Safety and Health (NIOSH) to develop detailed anthropometric specifications to replace the vague and inadequate ones in the existing regulations. A lack of anthropometry of the faces of U.S. civilians led us to use military surveys and to conduct a study of the faces of some Los Alamos personnel. Panels were developed using 16 males and 25 males and females.

For panels that will test full-facepiece respirators, the key dimensions of face length and face width are used. Using standard deviations (SD) of ±2 from the mean values, almost 95% of the U.S. population can be represented. The resulting range for face length is 94-133 mm, and for face width is 118-153 mm.

For testing half-mask respirators, lip length, with a size range of 35-61 mm, is substituted for face width. The use of other dimensions was considered but was rejected

because the large number of variables made it difficult to select test subjects.

We describe a sampling scheme for testing and retesting respirators that uses anthropometric test panels. NIOSH is to specify the permissible penetration level for a mask to be certified. Quantitative determinations of penetration offer more sensitive measurements of respirator efficiency than have been available previously.

The scheme of test panel selection has the following advantages: (1) Detailed specifications governing test subjects are given, whereas existing regulations give none. (2) In terms of face length and face width, the panels are representative of the faces of most of the U.S. working population. (3) Only two easily measured parameters are required in the selection of test subjects.

A more precise definition of the face could, of course, be achieved if more measurements were taken, but there must be a compromise. The use of the test panels described here should provide an improvement over current respirator testing methods.

II. PREVIOUS ANTHROPOMETRIC WORK

A. The Respiratory Protective Devices Manual

The Respiratory Protective Devices Manual,[2] published by the American Industrial Hygiene Association and the American Conference of Governmental Industrial Hygienists, devotes a chapter to the sizing and design of facepieces. The relationship of respirator dimensions to facial fit is discussed, and a five-size half-mask program is suggested which, hopefully, could accommodate most face lengths and lip lengths and which would have reasonable overlap of sizes. The program is largely theoretical and has not been used for mask design.

B. The Australian Facial Survey

In 1966, J. G. Hughes and O. Lomaev of the Division of Occupational Health and Pollution Control, New South Wales Department of Health, conducted an anthropometric survey of male faces. Eight facial measurements were taken with the intent to use the data in the design of half-mask respirators.[3]

Subsequent to the Hughes survey, Australian Standard Z18-1968 was adopted.[4] The standard includes a test panel of 10 men whose faces are selected on the basis of data from the Hughes survey. This panel is described in Sec. IV.

III. LASL ANTHROPOMETRIC SURVEY

No anthropometric survey, such as that made in Australia, has been made on the faces of U.S. workers. The bulk of facial data in the U.S. is based on samples from military personnel. Therefore, it was of interest to determine whether the military anthropometry would correlate with similar data from a civilian sample. We decided to conduct a limited survey that would: (1) provide the quantitative data for selection of specific test subjects, and (2) give an indication of how well the new data would correlate with published values from military sources.

A. Selection of Measurements

A conference was held at Los Alamos in January 1972 to decide on the number and types of facial measurements necessary for selection of subjects and for evaluation of the fit of respirators.[5] In addition to LASL and NIOSH attendees, there was an anthropologist from Webb Associates, Yellow Springs, Ohio, who at that time was preparing anthropometric criteria under a NIOSH contract.

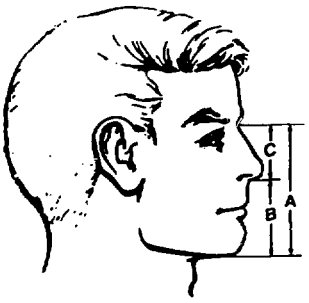
A list of 13 standard facial measurements, compiled by Webb Associates, is given in Table I. Although the 13 measurements are based on well defined facial landmarks, not all points of contact for a respirator facepiece are represented on the list. Additional measurements relating to the specific fit of full-face and half-masks are necessary. (Half-mask respirators cover the mouth and nose and fit under the chin; quarter-masks fit above the chin. The two types will be treated as one in this report.) The sealing edges of half-masks were examined while the devices were being worn. Full-face masks were studied by removing the viewing lenses and placing the mask on a head form. Paint was sprayed through the openings, leaving a clear area on the head form corresponding to the sealing edges of the mask. In consultation with Webb Associates, we prepared the expanded list of 21 facial measurements shown in Table II. Measurement numbers 4,8,11,12, and 18-21 were devised by us.

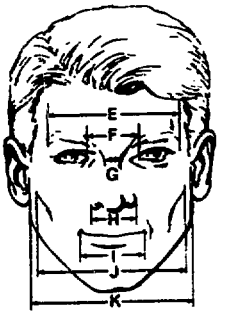
B. Survey Procedure

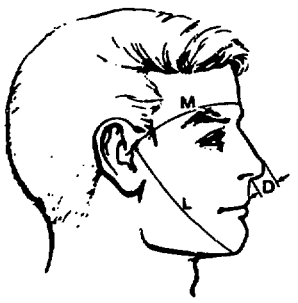
Two hundred men were measured in our survey. The subjects were selected from all available men who had been previously fitted with respirators. The data sheet

TABLE I

SIZE VARIABILITY FOR SELECTED ADULT FACIAL DIMENSIONS
(Source: Webb Associates)







Dimension	Male (mm)	Female (mm)
A. Face Length	108-133	94-119
B. Lower Face Length	58-80	45-66
C. Nasal Length	44-59	37-54
D. Nose Protrusion	17-29	—
E. Maximum Frontal Breadth	107-125	—
F. Interocular Breadth	28-39	—
G. Nasal Root Breadth	11-20	—
H. Nose Breadth	30-41	25-38
I. Lip Length	45-60	35-52
J. Face Breadth	132-153	117-141
K. Bigonial Breadth	104-131	91-113
L. Bitragion-Menton Arc	302-351	—
M. Bitragion-Frontal Arc	288-328	—

used is shown in App. A. Landmarks and measurement procedures are defined in App. B. Specially trained members of the Respirator Research and Development Section performed the measuring and recorded the data.

The LASL statistical group prepared computer programs for analyzing the data. Data were transferred directly from the data sheets to punch cards which were submitted for computer analysis. In addition to computing the means and other common statistical operations, a series of regression equations was prepared. These regressions were used to predict a measured value from other related values and served to locate impossible or incorrect values. Questionable values were corrected by remeasuring the subject, if possible, or by inserting the best computer-predicted value.

The procedure is similar to that described by E. Churchill of Webb Associates for editing and checking of anthropometric data.[6]

C. Results of Survey

Webb Associates suggested that in the absence of adequate facial data on U.S. workers, appropriate military

TABLE II

FACIAL MEASUREMENTS USED IN LASL ANTHROPOMETRIC SURVEY[a]

Measurement	Description	Purpose
1. Menton-Crinion Length	Distance from chin to hairline	Maximum length for full-face mask
2. Menton-Glabella Length	Distance from chin to eyebrows	Minimum length for full-face mask
3. Menton-Nasal Root Depression Length (face length)	Distance from chin to nasal root depression between the eyes	Standard face length for comparison with other surveys
4. Menton-Nasal Bridge Length	Distance from chin to bony projection of nose	Optimum length for half-mask
5. Lip Length	Width of lips, mouth closed	Standard measurement for comparison
6. Lip Length, Smiling	Width of lips, mouth smiling	Minimum width of half-masks
7. Nasal Bridge Breadth, Maximum	Maximum width of nasal bones	Design of nose of half-masks
8. Nasal Bridge Breadth, Minimum	Minimum width of nasal bones	Design of nose of half-masks
9. Nose Breadth	Width across nostrils	Half-mask design
10. Nose Length	Length from bottom of nose to nasal root depression	Half-mask design
11. Anterior Chin Projection-Nasal Bridge Length	Distance from forward projection of chin to nasal bones	Maximum length for quarter-masks
12. Horizontal Nose Protrusion	Distance that tip of nose projects from cheek	Design of half-masks
13. Maximum Frontal Breadth	Width across eyebrows	Minimum width inside top of full-face mask
14. Bizygomatic Breadth (face width)	Width across widest part of cheeks	Width of inside seal, full-face mask
15. Bitragion Breadth	Width of head across ears	Standard measurement
16. Bitragion-Minimum Frontal Arc	Arc between ears, across eyebrows	Standard measurement
17. Bitragion-Submandibular Arc	Arc between ears, under the chin	Standard measurement
18. Bizygomatic-Submandibular Arc	Arc between widest points on cheeks, under the chin	Circumference of lower seal, full-face mask
19. Bizygomatic-Menton Arc	Arc between widest points on cheeks, across the point of the chin	Circumference of lower seal, full-face mask
20. Bizygomatic-Minimum Frontal Arc	Arc between widest points on cheeks, across eyebrows	Circumference of upper seal, full-face mask
21. Bizygomatic-Crinion Arc	Arc between widest points on cheeks, across the hairline	Circumference of upper seal, full-face mask

[a]All measurements were selected to allow comparison with existing anthropometric surveys or to aid in mask design.

data could be used with considerable confidence. They offered us the most comprehensive available data for men in the form of summary statistics from the 1967 U.S. Air Force Anthropometric Survey.[7]

The nine measurements taken in common by the Air Force and LASL are listed in Table III. Six of the nine measurements show agreement to within approximately 2 mm, the LASL measurement error. Included in these six are the three dimensions that we believe to be of prime importance in defining test subjects: Bizygomatic Breadth (face width), Lip Length, and Menton-Nasal Root Depression Length (face length).

The means for Bitragion-Minimum Frontal Arc and Bitragion-Submandibular Arc show differences larger than 2 mm between the two surveys. As shown in App. B, arc measurements involve the use of a tape measure held against the face to measure the surface distance between defined landmarks. We were not able to reproduce any of the arc measurements with the precision achieved with the other measurements.

The close agreement between the two surveys gave us confidence that the facial sizes of our sample are not badly skewed.

Over 40% of the men measured for the LASL survey were Spanish-American. To determine whether there might be ethnic facial differences, Table IV was prepared. It gives the means for all subjects, for Spanish-Americans, and for the remainder. In no case do the mean values for any measurement change by more than about 2 mm.

IV. DEVELOPMENT OF TEST PANEL

A. Sampling Number

In the past, when various masks have been evaluated at Los Alamos, large numbers of test subjects have been used. For instance, when workers come to the Industrial Hygiene Group for periodic refitting of masks, they may be asked to try a new mask which is under evaluation. As

TABLE III

COMPARISON OF MALE FACIAL DIMENSIONS TAKEN BY USAF (1967) AND LASL (1972)
(Listed in order of increasing difference between the two surveys)

	Mean			Standard Deviation	
Measurement	USAF (mm)	LASL (mm)	Difference (mm)	USAF (mm)	LASL (mm)
Nose Length	51.3	51.6	0.3	3.7	4.3
Bitragion Breadth	142.5	143	0.5	5.6	6.0
Bizygomatic Breadth	142.3	142.9	0.6	5.2	5.7
Lip Length	52.3	51.4	-0.9	3.7	3.9
Menton-Nasal Root Depression Length	120.3	121.4	1.1	6.1	6.5
Nose Breadth	35.4	37.5	2.1	2.9	3.1
Maximum Frontal Breadth	116.0	112.6	-3.4	4.6	5.0
Bitragion-Minimum Frontal Arc	308.1	302.8	-5.3	10	10.7
Bitragion-Submandibular Arc	309.8	317.9	8.1	15.8	14.6
Age, yr	30	42.5	12.5	6.3	10
Height, cm	177.3	176.5	-0.8	6.2	6.7
Weight, lb	173.6	170.9	-2.7	21.4	21.6
Size of sample	2420	200			

TABLE IV

COMPARISON OF FACIAL DIMENSIONS AMONG MEASURED MALES (LASL)

Measurement	Mean, All (mm)	Mean, Non-Spanish-American (mm)	Mean, Spanish-American (mm)	SD, All Subjects (mm)	Mean SD, USAF (1967) (mm)	
1. Menton-Crinion Length	189.6	190.6	188.2	9.6		
2. Menton-Glabella Length	138.7	138.8	138.6	7.1		
3. Menton-Nasal Root Depression Length	121.4	121.1	121.5	6.5	120.3	6.1
4. Menton-Nasal Bridge Length	108.5	108.8	108.2	6.1		
5. Lip Length	51.4	51.4	51.5	3.9	52.3	3.7
6. Lip Length, Smiling	64.6	65.2	64.0	6.2		
7. Nasal Bridge Breadth Max.	34.7	34.5	34.9	3.2		
8. Nasal Bridge Breadth Min.	15.4	15.4	15.5	1.9		
9. Nasal Breadth	37.5	37.6	37.4	3.1	35.4	2.9
10. Nose Length	51.6	51.5	51.8	4.3	51.3	3.7
11. Anterior Chin Projection-Nasal Bridge Length	95.9	95.7	96.1	6.1		
12. Horizontal Nose Protrusion	33.3	33.8	32.7	3.1		
13. Maximum Frontal Breadth	112.6	112.9	111.9	5.0	116.0	4.6
14. Bizygomatic Breadth	142.9	143.1	142.5	5.7	142.3	5.2
15. Bitragion Breadth	143	143.5	142.2	6.0	142.5	5.6
16. Bitragion-Minimum Frontal Arc	302.8	304.8	300.3	10.7	308.1	10.0
17. Bitragion-Submandibular Arc	317.9	318.4	316.9	14.6	309.8	15.8
18. Bizygomatic-Submandibular Arc	301.6	302.8	300.1	16.2		
19. Bizgomatic-Menton Arc	299.0	300.1	297.6	14.0		
20. Bizygomatic-Minimum Frontal Arc	252.9	254.3	251.1	11.1		
21. Bizygomatic-Crinion Arc	279.4	281.5	276.7	12.0		
Number of Test Subjects	200	112[a]	86			

[a]Two additional subjects were classified "other."

many as 80 or more subjects have been used to test a single type of mask. In the certification of a respirator for commercial use, the U.S. has used zero to six subjects,[1] while Australia[4] and Great Britain[8] are currently using 10. A large sample obviously is desirable, for the larger the sample, the greater the confidence that the test results will apply to the total population.

The NIOSH Testing and Certification Laboratory (TCL) wants to increase the sample size used in respirator certification, but because of the time involved in a single man test, TCL is restricted to a sample size not greater than about 25. When such a small number of subjects is used to represent the wide variety of facial characteristics, the care used in selection of each subject is of prime importance.

B. Selection of Measurements for a Full-Face Mask Test Panel

Test panels selected by the anthropometric specifications developed in this report may possibly be used by NIOSH in respirator testing and certification, and the U.S. Atomic Energy Commission and other governmental agencies may also use the panels to evaluate devices that lack NIOSH certification. In addition, manufacturers of respiratory equipment can make use of the facial sizes described here in their design of prototypes. Not all of these organizations can be expected to have anthropological expertise, and this affected our selection of anthropological criteria for the panels.

The 21 facial measurements shown in Table II were examined with the goal of selecting the criteria most appropriate for evaluating facepiece-to-face seal, while retaining reproducibility of measurement. The arc measurements, numbers 16-21, are extremely difficult to reproduce and were deleted from consideration. Measurement 1 is based on the hairline, and shows great variability between men. It was included in the original 21 measurements because we wanted some data on the prevalence of low hairlines which might interfere with the seal of some full-face masks. However, measurement 1 will not be included in the panel criteria because hairline interference can easily be determined visually during a fitting.

Strong correlations between measurements, as shown in App. C, will provide economy in the selection of measurements, in that closely related measurements may be substituted for each other with some confidence.

Measurement 3, Menton-Nasal Root Depression Length (face length), is a reproducible measurement, and a great deal of data is available on it.[3,6,7] Measurement 3 correlates strongly with measurement 2, Menton-Glabella Length, which is the minimum length that a full-face mask can be without interfering with the eyebrows. In addition, measurement 3 is strongly correlated with measurement 4, Menton-Nasal Bridge Length. Measurement 4 is the optimum length for a half-mask respirator. A mask longer than this will interfere with eyeglasses, and a shorter mask will lie lower on the nose and possibly interfere with breathing. We include face length as one of the selection criteria for the test panels. Measurement 3 is used as a key dimension in the selection of subjects for testing the Australian Respirator Standard Z18[4] and also in the design of the Air Force MC-1 oxygen mask.[9]

For the selection of a width measurement, we examined the sealing surfaces of full-face masks to determine which dimension best describes width. There is a standard face-width measurement which lies within the seal of all full-face masks: measurement 14, Bizygomatic Breadth. Two other width measurements were also examined: 13, Maximum Frontal Breadth (distance across the eyebrows), and 15, Bitragion Breadth (distance between the two ear holes). Measurement 15 lies outside the sealing surface of the mask, but has been used as a dimension in most facial surveys and so was included for comparative purposes. Also, measurement 15 correlates well with 14 and either could be used, but using both would be superfluous. Measurement 13 is of some use but is less relevant to overall face width than measurement 14, which was chosen as the key width. Australia also uses measurement 14 as the width measurement for its panel.

The low correlation between length and width (0.236) implies the occurrence of almost as many long-narrow faces as long-wide. Table V shows the frequency of all combinations of length and width in the Air Force surveys.[6,7] One of the limitations of the Australian test panel dimensions shown in Table VI is the inclusion of only the harmonic relationship between length and width (short length and width, medium length and width, and long length and width). Almost half of the possible length-width combinations are missing in the Australian scheme.

C. Panel Limits

Designers of devices and equipment for humans have traditionally used less than 100% of the population as a design goal. As a rule, a maximum of 90-95% of the population is used unless custom-made devices are being considered. For a normal distribution, the mean value for a given variable ±2 SD will include approximately 95% of the population in terms of that variable. For face length, the mean (using the 1967 Air Force data) is 120.3 mm, and the SD is 6.1. Some 95% of the distribution for face length will lie in the range of 108-133 mm. The mean for face width is 142.3 mm and its SD is 5.2, with 95% of the subjects in the range of 132-153 mm.

Any subject with facial dimensions within the inner box shown in Table V would be an acceptable test subject under our proposal. If subjects are chosen at random from within the limits, however, the majority will fit into the center of the rectangle because the frequency of occurrence of men in the center is greater. To ensure adequate representation of all combinations of length and width, we have arbitrarily divided the bivariate table into a series of nine size categories. Table VII indicates the percentage of the sample that occurs in each category. Twenty-nine percent of the subjects are found in the center of the table and less than 4% in two of the corner boxes. Although not perfect, this method appears to assure adequate coverage of the facial variation in the population.

D. Number of Test Subjects in Panel

The number of test subjects to be drawn from each size category, or box, as recommended by Webb Associates,[10] is shown in Table VIII. Sixteen male test subjects were used in early test panel evaluations. When test panels were later developed for men and women, the number of subjects was increased to 25.

TABLE V

BIVARIATE FREQUENCY TABLE FOR FACE LENGTH AND FACE WIDTH[a,b]
(Combined data from Refs. 6 and 7)

(Heavy lines enclose the distribution within the limits of face length 108-133 mm and face width 132-153 mm)

Face Width (mm)

Face Length (mm)	108.5	110.5	112.5	114.5	116.5	118.5	120.5	122.5	124.5	126.5	128.5	130.5	132.5	134.5	136.5	138.5	140.5	142.5	144.5	146.5	148.5	150.5	152.5	154.5	156.5	158.5	
142.5																		/ 1						/ 1			/ 2
140.5															/ 1			/ 1	/ 2								/ 4
138.5																			/ 1		/ 1	/ 1					/ 3
136.5											/ 1					/ 1		/ 2	/ 1	/ 3	/ 1		/ 1	/ 1			/ 11
134.5												/ 1			/ 1	/ 2	/ 2	/ 3	/ 2	/ 2	/ 4	/ 4					/ 21
132.5													/ 3	/ 4	/ 5	/ 7	/10	/ 4	/ 6	/ 4	/ 2						/ 45
130.5													/ 2	/ 3	/ 5	/ 5	/ 9	/15	/ 9	/11	/ 4	/ 4		/ 1	/ 1	/ 1	/ 70
128.5												/ 1	/ 1	/ 4	/ 7	1/14	/17	/16	/13	/15	/16	/ 4	/10	/ 5	/ 1	/ 1	1/ 125
126.5								1/				1/	/ 2	/ 3	/ 9	/12	/22	/38	/33	/27	/14	/ 8	/ 7	/ 5	/ 2		2/ 182
124.5										1/		1/ 4	/ 2	/14	/14	/20	1/39	/37	/45	/35	/15	/11	/11	/ 8	/ 2	/ 1	3/ 256
122.5										1/	/ 1	1/ 1	2/ 7	1/11	/18	/37	2/48	/54	/46	/32	/26	/15	/ 7	/ 2	/ 1		7/ 306
120.5							2/	1/	3/	1/	2/ 1	3/ 3	1/ 6	3/12	2/36	/40	/43	/61	1/38	/36	/35	/11	/12	/ 1			19/ 335
118.5			1/				1/	1/	3/	3/	5/ 1	7/ 4	3/13	7/11	7/32	1/19	1/45	/47	/48	/30	/ 9	/ 4	/ 5				40/ 268
116.5				1/	3/	2/	3/	4/	5/ 1	5/	5/ 1	12/ 2	6/10	9/15	4/27	2/32	4/35	1/34	/39	1/27	/12	/ 6	/ 1	/ 4			67/ 246
114.5		1/			1/		5/	6/	9/ 1	11/ 2	7/ 1	13/ 1	3/14	14/22	3/26	6/30	3/39	1/34	2/24	/15	/13	/ 4		/ 2	/ 1	/ 1	85/ 230
112.5							6/	3/	15/	18/ 1	12/ 1	26/ 2	21/ 4	20/11	10/12	4/14	5/20	1/23	2/22	/ 9	/ 8	/ 5	/ 1		/ 1		143/ 134
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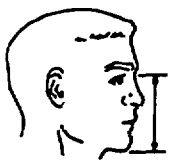
106.5		2/	2/	2/	3/	1/	17/	12/	23/1	27/	25/ 1	48/	20/	27/ 1	12/ 2	10/ 1	5/ 5	/ 2	/ 2	/ 1	/ 1		/ 1				246/ 18
104.5		2/	1/	6/	1/	2/	13/	18/	34/	39/ 1	29/	55/	26/	23/	15/ 2	10/ 1	2/ 1	2/		/ 3	1/						276/ 8
102.5		1/		5/	3/	3/	9/	14/	26/	36/	12/	46/	22/ 1	23/	5/ 1	3/ 2	5/	1/	2/ 1								216/ 5
100.5				3/	2/		11/	9/	19/	26/	22/	26/	10/	23/	7/	2/	1/		1/								162/
98.5			1/	2/	3/		9/	8/	17/	11/	14/	19/	4/	5/	2/		1/		1/ 1		1/						98/ 1
96.5				1/		1/	2/	2/	5/	9/	9/	10/	4/	6/	4/		1/										54/
94.5			2/			2/	6/	2/	6/	6/	2/	6/	3/	4/	1/												40/
92.5							2/	1/	5/	3/	1/	7/	2/	2/													23/
90.5	1/							1/		3/	4/	1/	1/		1/	1/											13/
88.5								1/	1/																		2/
86.5										1/																	1/
	1	6	8	24	23	18	113	102	216 3	249 4	188 9	347 20	186 66	207 128	100 213	52 252	43 356	9 404	9 347	2 259	2 174	81	59	32	9	4	1905 2420

[a] Numbers in each box refer to Female/Male.

[b] All values shown are category midpoints.

TABLE VI

FACIAL DIMENSIONS OF AUSTRALIAN TEST PANEL

Group	Number of Persons in Group	Facial Dimensions (mm)	
		 Bizygomatic Diameter	 Menton-Nasal Root Depression Length
A	3	128-136	109-111
B	9	137-146	112-123
C	3	147-154	124-133

METHOD OF SELECTING PERSONNEL FOR ASSEMBLED RESPIRATOR TESTS

METHOD OF SELECTION. To obtain as adequate a coverage of facial size and contour as possible, eliminating the unusual or abnormal faces, the testing authority shall select 15 male persons aged between 18 and 65 years who are of the appropriate ethnic type. The facial dimension of the persons chosen should fit into the groups set out in the table.

Note: These dimensions were calculated from the means and standard deviations ascertained in the limited anthropometric survey of 538 persons carried out by the Division of Occupational Health, N.S.W. Department of Public Health.

SPECIFIC REQUIREMENTS. The testing authority should be guided also by the following principles in selecting the test panel

(i) The panel should exclude persons with scars or other skin blemishes in the area contacted by the face piece if such blemishes are likely to interfere with the result of the fitting test

(ii) Panel members must be freshly shaven at the time of the test.

(iii) The panel should exclude persons whose facial contours are distorted due to the loss of teeth and who are not fitted with dentures.

(iv) The panel should exclude persons with misshapen noses or abnormal facial contours.

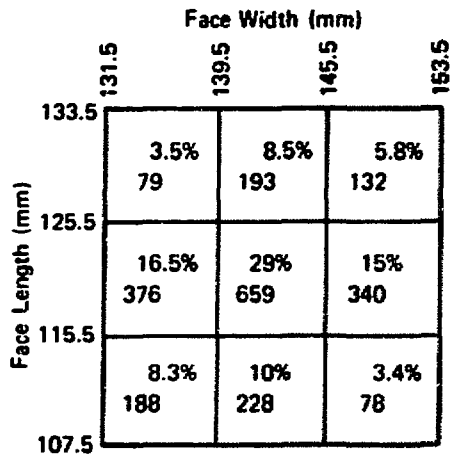
(v) The panel should be distributed as evenly as possible by visual inspection between thin, medium and well fleshed persons but excessively thin, excessively fat or heavily jowled persons should be avoided.

SELECTION OF TEST PANEL. The panel selected in accordance with the above paragraphs should then be photographed both in full face and profile and a copy of each photograph (not smaller than 6 in. by 4 in. glossy paper) should be supplied to the manufacturer of the respirator. The manufacturer may reject not more than one person from Groups A and C and not more than three persons from Group B. The final test panel of 10 persons will thus comprise two persons from Groups A and C and six from Group B.

TABLE VII

NINE SIZE CATEGORIES OF MALE TEST PANEL[a]

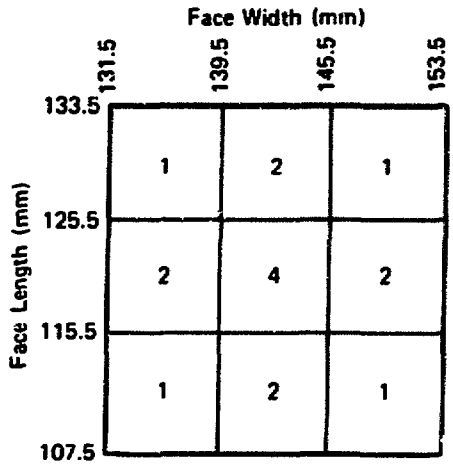
(Each category contains percentage of population represented and numbers of subjects)



[a]From USAF Anthropometric Survey (1967)
Total men measured - 2420
2273 men in sample - 93.9% of the total

TABLE VIII

SIXTEEN-MALE TEST PANEL FOR FULL-FACE MASKS



E. Limitations on Test Subjects

Any male whose face length and face width fit within the panel limits of Table VIII is acceptable, with the following limitations. Subjects should be freshly shaven, with less than one day's beard growth. Because of potential mask leakage, facial hair, such as sideburns, is permitted only if the hair does not interfere with the seal of the mask. Facial disfigurements, scars, broken bones, or other characteristics that may adversely affect the mask-to-face seal must be evaluated by the personnel doing the respirator testing. If there is any doubt about the subject's suitability, another man should be chosen.

V. PANEL FOR TESTING FULL-FACE MASKS

A. Available Tests

LASL's quantitative man test results from past years can be used to evaluate our test panel scheme once the subjects have been classified by face length and face width. A recently completed study of self-contained breathing apparatus (SCBA)[11] performed for the AEC Directorate of Regulatory Standards was used for the first evaluation of the LASL man test panel.

B. Test Subjects

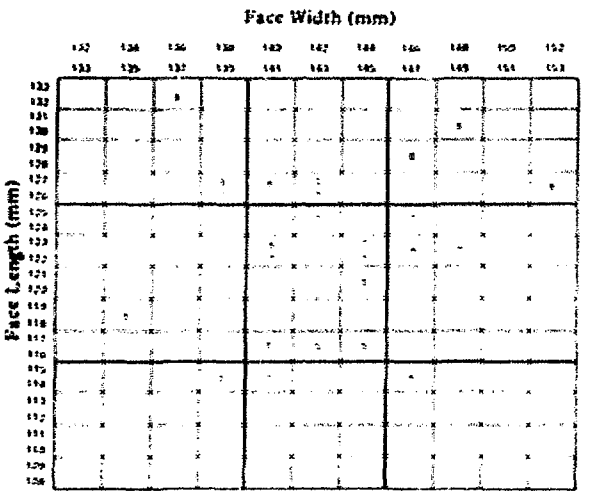
Los Alamos firemen, who are familiar with SCBA, were used as test subjects. Thirty-one firemen, out of a large number whose faces had been measured, were selected. As shown in Table IX, all size ranges required in the LASL test panel were represented, although only one man was located in the bottom center box. The other subject called for in that box is missing because the SCBA study was completed before the LASL test panel scheme had been developed. Other boxes contain more subjects than necessary, but because all sizes are present, we decided to accept the SCBA test results for the initial evaluation of the panel system. Of the 31 men, 4 were out of the range of 95% of the population, and were not used.

C. SCBA and Test Apparatus

SCBA consists of a full-face mask, compressed air tank, and regulator. Demand mode of operation was used in which the wearer must inhale and draw negative pressure in the facepiece before the regulator will supply air. Similar conditions exist inside a full-face air-purifying respirator, with the only major difference being that in the latter case outside air is drawn through filters or sorbents by the action of inhalation.

TABLE IX

SCBA TEST PANEL



Subjects tested each of seven models while inside a test chamber with a concentration of 100 mg/m^3 of 0.3 μm thermally generated dioctyl phthalate (DOP), a standard test aerosol. Each mask had been modified by the addition of a probe through which an 8-liter/min sample could be removed and analyzed. A forward light scattering photometer was used to detect percentage of DOP penetrating the mask. Results were recorded on a strip chart which indicated a changing leak rate–greater on inhalation and smaller on exhalation. Subjects were asked to perform exercises to simulate work: normal breathing, deep breathing, turning the head from side to side, moving the head up and down, and frowning. Leakages were averaged for all exercises. If the average penetration of a mask on one subject exceeded 0.5%, that test was counted as a failure for protection against 100 times the maximum permissible concentration of a toxic substance, following the Bureau of Mines Schedule 21B.[12]

D. Test Results

Table X is a summary of the test results for the seven masks used. Because the SCBA panel contained 27

TABLE X

SCBA MASK PENETRATION >0.5%

Mask	No. Penetrations among 27 Subjects	No. Penetrations among 15 Subjects
A	8	5
B	8	4
C	10	5
D	2	2
E	1	1
F	1	0
G	1	1

subjects and the LASL system required only 16, a second evaluation was made, using only 15 subjects out of the 27. (One box lacked one of the two subjects called for, so that only 15 men were available for testing.)

The relative standings of the masks are unchanged, the worst performing masks have the most failures in both columns, and the best have the fewest failures.

In an attempt to determine a pattern to the failures, Table XI was prepared. The percentage of mask leakage is indicated in the box appropriate to the facial dimensions of the subject. Although 27 subjects tested each of the masks, those whose masks did not show >0.5% leakage are not included in the table. It is difficult to find a pattern to the failures, but there is a striking difference between the results of masks C and D. These two masks, from the same manufacturer, differ only in the composition of the rubber used. Mask C is made with a hard neoprene, whereas D uses a much softer silicone material.

VI. PANEL FOR TESTING HALF-MASKS

The test panel discussed in Sec. IV was intended to select subjects to test only full-face masks. Face width, measurement 14, is not appropriate for testing half-masks because the seal of the half-mask does not lie on any facial contour that can be predicted by knowing the face width. Lip length (mouth width), measurement 5, has been suggested in the Respiratory Protective Devices Manual[2] as a key measurement. Also, lip length was used as one of the sizing criteria of the MC-1 oxygen mask.[9] If a half-mask is to seal properly it must be wider than the lips. Measurement 6, the mouth width during smiling, is useful because some people can temporarily break the seal of a half-mask by smiling. However, a mask can be designed with sufficient width that the seal will not be cracked. We have selected lip length and face length as the selection criteria for testing half-masks.

The panel for half-masks will use face length and lip length, derived in the same way as for the full-face panel. The 1967 Air Force survey lists a mean value for lip length of 52.3 mm, with SD of 3.7. Ninety-five percent of the males have lip lengths between 45 and 60 mm. Table XII shows nine size categories with the population and percentage for face length and lip length found in the Air Force survey. A 16-man panel derived from these figures is shown in Table XIII. Table XIV is a bivariate table showing face length and lip length from the two Air Force surveys.[6,7] Many of the subjects acceptable for the full-face panel can be used on the half-mask panel, although additional subjects will be needed if all size categories are to be filled.

VII. TEST PANELS OF MALES AND FEMALES

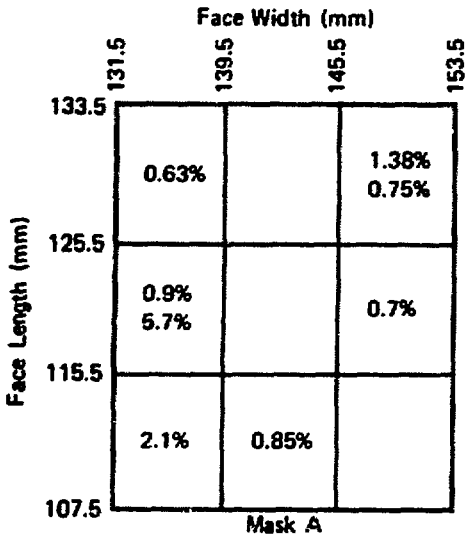
All commercially available respirators are presently made in only one size and are designed to fit only men. In general, women have shorter and narrower faces than men and consequently find it more difficult to obtain adequate protection with commercial respirators. NIOSH asked us to develop panels representative of the entire working population, male and female. We have developed two such panels, one for full-face masks, and the other for half-masks.

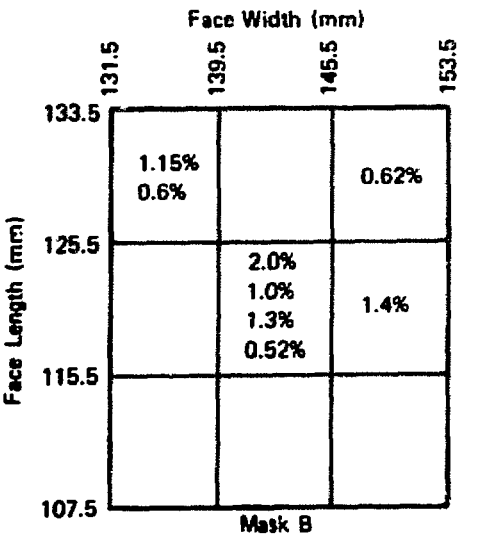
A. Full-Face Respirator Test Panel Derivation

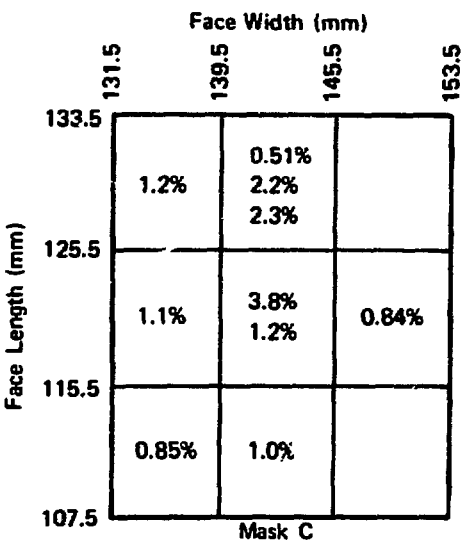
Face length and face width will be used to describe the panel subjects for full-face mask testing. Data on women are available from the 1968 survey of Air Force women.[6] The relationship of male and female faces can be seen by reexamining Table V. Males predominate in the region of longer face length and wider face width, and females predominate in the region of shorter face length and narrower face width. For a test panel consisting of both males and females, the lower limits were calculated by taking the mean values for face length and face width for the women and subtracting 2 SD. Upper limits are calculated from the male mean values plus 2 SD. Slight adjustments were then made to allow the use of equal size

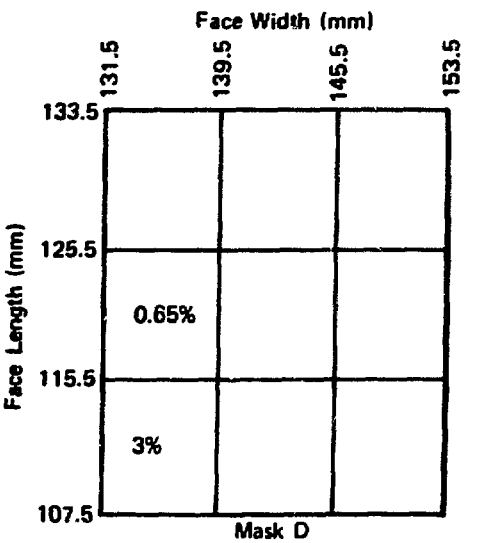
TABLE XI

TEST RESULTS ON INDIVIDUAL FULL-FACE MASKS[a]
(27 Subjects)

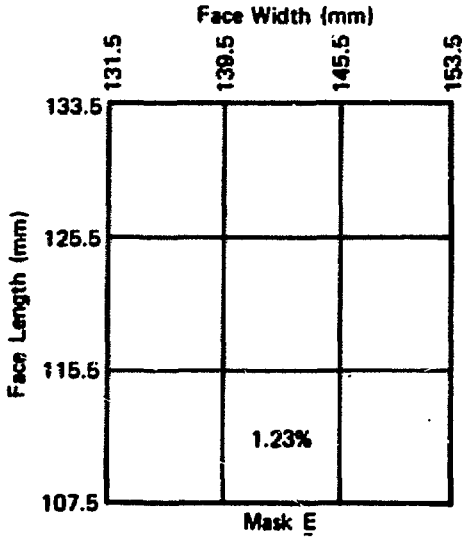


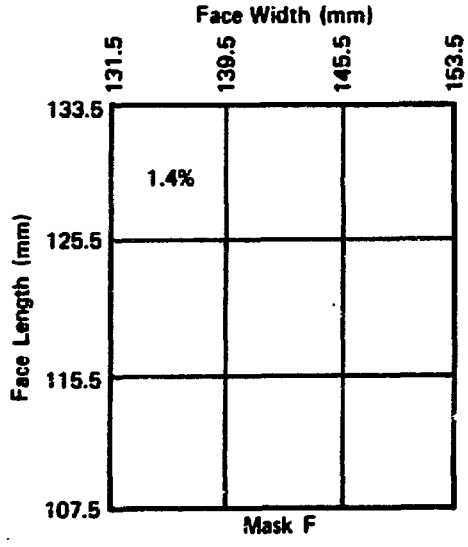






[a]Only subjects with leakage >0.5% included.


Face Width (mm)
131.5
139.5
145.5
153.5
133.5
125.5
115.5
107.5
Face Length (mm)
1.23%
Mask E


Face Width (mm)
131.5
139.5
145.5
153.5
133.5
125.5
115.5
107.5
Face Length (mm)
1.4%
Mask F

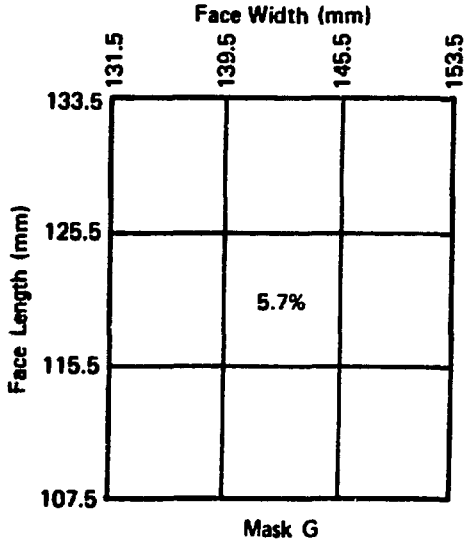
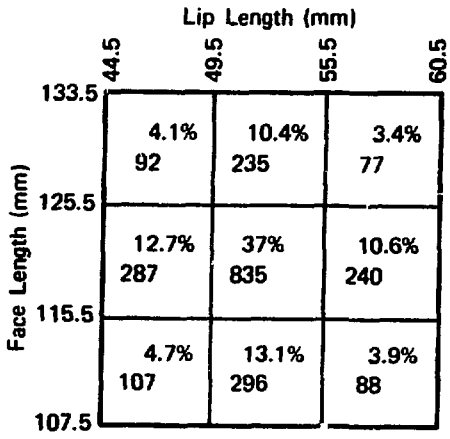

Face Width (mm)
131.5
139.5
145.5
153.5
133.5
125.5
115.5
107.5
Face Length (mm)
5.7%
Mask G

TABLE XII

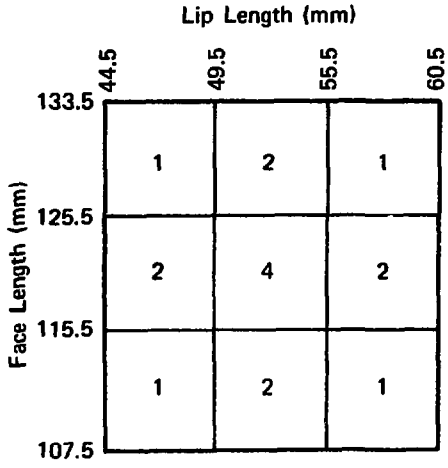
POPULATION BY FACE LENGTH AND LIP LENGTH[a]



[a]From USAF Anthropometric Survey (1967) 2420 men measured

TABLE XIII

SIXTEEN-MALE TEST PANEL FOR TESTING HALF-MASKS



intervals. Table XV shows the limiting face lengths (94-133 mm) and face widths (118-153 mm) for a male-and-female full-face test panel. The table is divided into length increments of 10 mm and width increments of 9 mm, thereby creating a 16-category panel. The number and percentage of the females (F) and males (M) are given, as are the totals (T). The distribution is the same as that to be expected in the general population. To simplify subject selection, the 6 least populated categories are deleted, leaving a 10-category table representing about 91% of the total population, male and female. Table XVI shows the distribution of 25 subjects among the 10 size categories--a distribution typical of the general population. For testing purposes, we assume that a male and a female face with the same two key dimensions are equivalent. Therefore, the sex preferences listed in each box are advisory only, and members of the other sex may be substituted.

A single size of mask made to fit the entire population will be tested on the entire panel. For multiple-size masks the panel will be subdivided into smaller units as detailed in Sec. VIII.

B. Half-Mask Panel Derivation

Face length and lip length are the key dimensions for selecting faces to test half-masks. The limits for face length are the same as those for the full-face panel. Limits for lip length are 35-60 mm, and are derived by adding 2 SD to the male mean value and subtracting 2 SD from the female mean. In Table XVII the limits for lip length are adjusted to allow equal intervals of 9 mm, producing a 12-category sample. The expected population in each size category is shown. The upper left and lower right boxes contain only about 0.5% of the population and are deleted. Over 95% of the population is represented in terms of face and lip length in the 10 remaining boxes. Table XVIII gives the distribution of 25 subjects over these 10 boxes. This panel is suggested for testing a single-size mask. Multiple-size masks will use the scheme described in Sec. VIII.

VIII. PASS-FAIL CRITERIA FOR RESPIRATOR ACCEPTANCE

A test protocol is needed for use with the test panels. The anthropometric specifications given in this report attempt to describe a complex facial shape in terms of only two variables. Other factors, such as a narrow nose, weak chin, or other undetected conditions, can result in

TABLE XIV

BIVARIATE FREQUENCY TABLE FOR FACE LENGTH AND LIP LENGTH[a,b]
(Combined data from Refs. 6 and 7)

(Heavy lines enclose the distribution within the limits of face length 108-133 mm and lip length 45-60 mm)

Lip Length (mm)

Face Length (mm)	31.5	33.5	35.5	37.5	39.5	41.5	43.5	45.5	47.5	49.5	51.5	53.5	55.5	57.5	59.5	61.5	63.5	65.5	Totals
142.5								/ 1							/ 1				/ 2
140.5								/ 1		/ 1	/ 1		/ 1						/ 4
138.5										/ 1		/ 1	/ 1						/ 3
136.5										/ 1	/ 2	/ 2	/ 3	/ 3					/ 11
134.5	1							/ 2		/ 3	/ 5	/ 4	/ 3	/ 3	/ 1				/ 21
132.5							/ 1	/ 4	/ 5	/ 5	/ 8	/11	/ 5	/ 3	/ 1	/ 2			/ 45
130.5						/ 1		/ 2	/ 4	/11	/12	/16	/14	/ 6	/ 2	/ 2			/ 70
128.5							/ 2	1/ 2	/11	/23	/28	/29	/16	/ 8	/ 3	/ 3			1/ 125
126.5						1	/ 4	2/ 9	/18	/26	/31	/35	/35	/16	/ 5	/ 2			2/ 182
124.5						/ 2	/ 1	1/ 7	/18	1/51	/64	/57	1/34	/19	/ 4	/ 1			3/ 258
122.5					2/	1/ 1	2/ 5	1/10	/20	/58	/58	/68	1/39	/30	/10	/ 2	/ 4	/ 1	7/ 306
120.5					2/ 2	3/ 3	2/ 9	3/ 8	2/29	3/44	3/67	1/74	/57	/26	/11	/ 4	/ 1		19/ 335
118.5				1/		7/ 1	3/ 6	9/11	10/31	3/51	5/50	/50	2/39	/20	/ 8			/ 1	40/ 268
116.5			2/	8/	4/	10/	9/ 4	11/12	12/21	5/42	4/51	2/44	/39	/20	/10	/ 3			67/ 246
114.5			3/	3/	9/	14/	10/ 5	19/11	13/19	9/42	1/49	2/45	2/32	/20	/ 5		/ 1		85/ 230
112.5	2/		3/	7/	10/	26/ 1	22/ 1	32/ 8	19/12	11/23	9/20	2/32	/22	/10	/ 2	/ 2	/ 1		143/ 134
110.5		2/	1/	11/	25/	33/	38/ 3	23/ 3	27/17	16/13	9/23	4/15	1/14	1/ 8	/ 4	/ 2		/ 1	191/ 103
108.5		2/	8/	9/	24/	53/	30/ 1	40/ 1	25/ 3	21/ 4	3/ 8	1/15	/ 6		/ 5	/ 2			216/ 45
106.5		2/	6/	16/	33/	49/	44/	43/	17/	16/ 4	15/ 6	4/ 2	1/ 2	/ 2	/ 1	/ 1			246/ 18
104.5	1/	4/	8/	18/	28/	53/	50/	50/	30/ 1	16/ 1	12/ 2	2/ 2	4/ 2						276/ 8
102.5	2/	1/	4/	21/	20/	48/	33/	39/	26/ 1	13/ 1	4/ 2	3/ 1	1/	1/					216/ 5
100.5			7/	12/	20/	34/	16/	25/	24/	13/	6/	3/		2/					162/
98.5		1/	3/	6/	17/	25/	14/	20/	6/	4/	1/	1/			/ 1				98/ 1
96.5			2/	3/	5/	17/	8/	9/	4/	2/	3/		1/						54/
94.5				4/	6/	10/	6/	7/	4/	3/									40/
92.5			1/	1/	5/	5/	2/	5/	3/	1/									23/
90.5					3/	1/	5/	4/											13/
88.5				1/				1/											2/
86.5						1/													1/
Totals	5/	12/	48/	121/	213/ 3	390/ 10	294/ 42	345/ 92	222/ 210	137/ 405	75/ 487	25/ 503	14/ 364	4/ 194	74	26	7	3	1905/ 2420

[a] Numbers in each box refer to Female/Male.

[b] All values shown are category midpoints.

TABLE XV

MALE/FEMALE PANEL FOR TESTING OF FULL-FACE MASKS
(Combined data from Refs. 6 and 7)

Face Width (mm)

Face Length (mm)	117.5	126.5	135.5	144.5	153.5
133.5		39 M 1.7%	356 M 15.3%	253 M 10.8%	
	2 F 0.1%	2 F 0.1%	2 F 0.1%		
	2 T <0.1%	41 T 1.0%	358 T 8.6%	253 T 6.1%	
123.5	2 M 0.1%	139 M 6.0%	836 M 35.8%	396 M 17.0%	
	55 F 3.1%	115 F 6.4%	39 F 2.2%	2 F 0.1%	
	57 T 1.4%	254 T 6.1%	875 T 21.1%	398 T 9.6%	
113.5	1 M <0.1%	46 M 2.0%	190 M 8.1%	68 M 2.9%	
	295 F 16.3%	612 F 33.8%	132 F 7.3%	5 F 0.3%	
	296 T 7.1%	658 T 15.9%	322 T 7.8%	73 T 1.8%	
103.5		1 M <0.1%	4 M 0.1%	1 M <0.1%	
	190 F 10.5%	319 F 17.6%	36 F 2.0%	2 F 0.1%	
	190 T 4.6%	320 T 7.7%	40 T 1.0%	3 T <0.1%	
93.5					

F = 1808 94.9%
M = 2332 96.4%
T = 4140 95.7%

M = Males
F = Females
T = Total

TABLE XVII

MALE-AND-FEMALE PANEL FOR TESTING OF HALF-MASKS
(Combined data from Refs. 6 and 7)

Lip Length (mm)

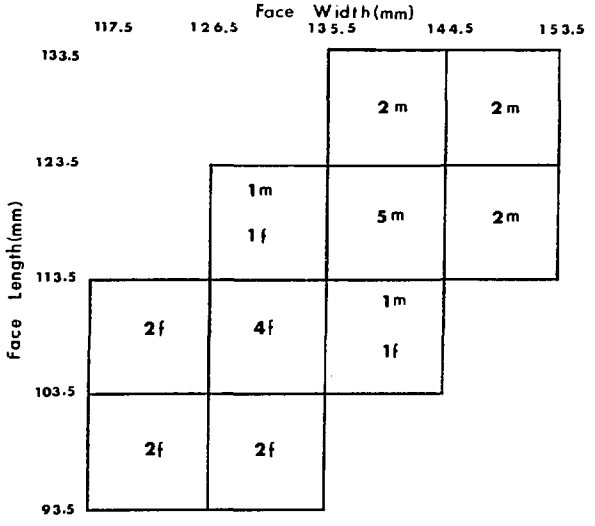
Face Length (mm)	34.5	43.5	52.5	61.5
133.5	8 M 0.3%	343 M 14.5%	325 M 13.8%	
		5 F 0.3%	1 F	
	8 T 0.2%	348 T 8.3%	326 T 7.7%	
123.5	17 M 0.7%	704 M 29.8%	652 M 27.6%	
	83 F 4.5%	125 F 6.8%	10 F 0.5%	
	100 T 2.4%	829 T 19.7%	662 T 15.7%	
113.5	2 M 0.1%	153 M 6.5%	149 M 6.3%	
	526 F 28.4%	513 F 27.7%	20 F 1.1%	
	528 T 12.5%	666 T 15.8%	169 T 4.0%	
103.5		4 M 0.2%	2 M 0.1%	
	306 F 16.5%	248 F 13.4%	12 F 0.6%	
	306 T 7.3%	252 T 6.0%	14 T 0.3%	
93.5				

F = 1849 97.1%
M = 2359 97.5%
T = 4208 97.3%

F = Females
M = Males
T = Total

TABLE XVI

MALE-AND-FEMALE, 25-MEMBER PANEL FOR TESTING OF FULL-FACE MASKS



poor respirator performance. However, test subjects with such conditions cannot necessarily be detected before testing.

It is not likely that a poor device would survive the proposed battery of tests. The following procedure should identify good and poor devices, and permit retesting of questionable ones.

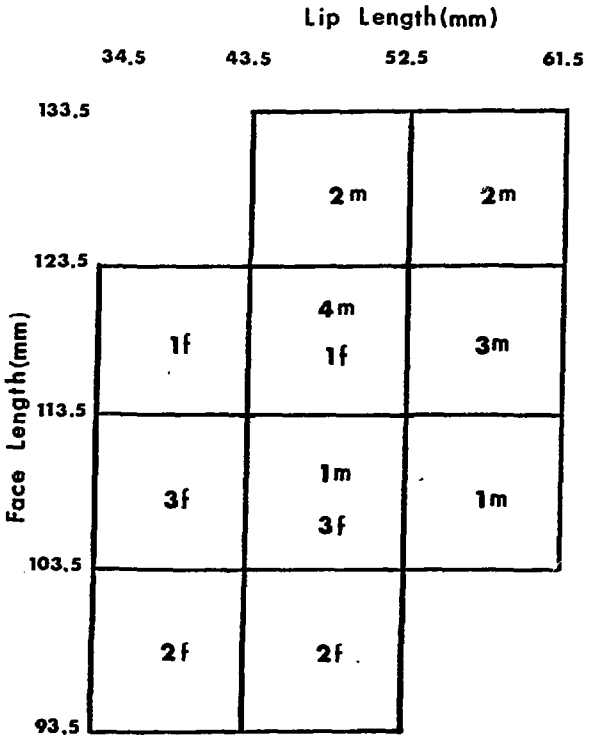
A. Sequential Testing Scheme

This procedure refers to the testing of a single-size mask by the entire panel. In this case, 5 identical masks are submitted for testing on 25 subjects, with 5 subjects testing each mask. The testing scheme is shown in Table XIX. In step 1, each subject is tested on one mask. If three failures occur at this time, the mask is rejected and testing ends. If there are no failures, the mask is accepted. In the event of one or two failures, retesting is done in step 2.

The one or two subjects with masks that failed in step 1 are retested on two other masks in step 2. If there are no failures here, the mask is accepted. If there are any failures, additional testing is performed in step 3. Failures

TABLE XVIII

MALE-AND-FEMALE, 25-MEMBER PANEL FOR TESTING OF HALF-MASKS



recurring in steps 1 and 2 are suspect--it is difficult to determine if the mask is at fault or if the subject is unrepresentative. Therefore, provision is made to substitute additional subjects from the same size category as the subject who failed. The number of additional subjects substituted should equal the number of subjects originally in that category (either 1, 2, 3, 4, or 5).

Ultimately, all tests must be successful if a mask is to be accepted. A minimum of 25 tests is required for acceptance, but a poor device can be rejected in as few as 3 tests.

B. Multiple-Size Masks

One size of mask cannot be expected to provide adequate protection for the large range of facial sizes represented in the test panels. Examples of modified test panels for evaluating multiple-size masks follow. Table XX shows the distribution of test panel members for a two-size mask. The larger size, designated size 1, is to be worn by 13 panel members, and size 2 is to be worn by 12 members. A three-size scheme, with considerable overlap between panel constituents, is shown in Table XXI. In this case, size 1 is worn by 12 subjects, size 2 by 17, and size 3 by 11 subjects. The total number of subjects remains at 25 although 40 individual tests are required.

We have assumed that each size is designed to fit all the subjects within the designated facial-size categories.

The performance requirements are such that the development of multiple-size masks may be necessary. We have not considered the requirements of test subjects whose faces lie outside the panel limits. However, we believe such persons stand a better chance of being accommodated by multiple-size masks than by the single sizes now on the market.

IX. CONCLUSION

This report describes anthropometric studies conducted from March 1972 through June 1973 by LASL's Respirator Research and Development Section. For the first time in this country, anthropometric specifications for male and female test subjects are being considered for the approval testing of respirators. Using the techniques described in this report, it should be possible to estimate the quality of facepiece fit on a large percentage of the population without testing large numbers of people.

REFERENCES

1. Federal Register 37, No. 59 (March 25, 1972), pp. 6244-6271.
2. "Facepieces," in *Respiratory Protective Devices Manual*, (American Industrial Hygiene Association and American Conference of Governmental Industrial Hygienists, Ann Arbor, 1963), Chap. 3, pp. 19-34.
3. J. G. Hughes, O. Lomaev, "An Anthropometric Survey of Male Facial Sizes," Am. Ind. Hyg. Ass. J. 33, 71-78 (February 1972).
4. "Respiratory Protective Devices," Australian Standard AS Z18-1968, (Standards Association of Australia, Sydney).
5. J. A. Pritchard, "Notes on LASL Conference on Anthropometric Facial Measurements in Relation to Various Types of Respirator Facepieces," Los Alamos Scientific Laboratory report LA-4907-MS (January 1972).
6. C. E. Clauser et. al., "Anthropometry of Air Force Women," Aerospace Medical Research Laboratory, Wright-Patterson AFB, Ohio, report AMRL-TR-70-5 (April 1972), pp. 36-39, and 346.
7. United States Air Force Anthropometric Survey - 1967. Unpublished. Wright-Patterson AFB, Ohio.
8. "Respirators for Protection Against Harmful Dusts and Gases," British Standard BS 2091:1969.

21. Bizygomatic-Crinion Arc. Using the zygomatic landmarks of measurement 18, pass the tape over the midpoint of the hairline.

APPENDIX C

CORRELATION COEFFICIENTS*

The correlation coefficient, often designated by r, is the most common measure of the degree of interrelationship between two numbers, values, etc. r varies between 0.0 and 1.0. A judgment as to whether a correlation coefficient is large or small, meaningful or not, depends upon some knowledge or feeling for the data being analyzed. For the purpose of interpreting correlations of anthropometric data, the following three scales may be helpful.

(1) A value of r = 0.0 means no correlation. There is no discernible relationship between two values. If one value is large, the other value has an equal chance of being large or small.

(2) A value of r = 0.5 corresponds roughly to the correlation, in adults, of height to weight.

(3) A value of r = 1.0 is a perfect, exact relationship.

TABLE C-I

SELECTED[a] CORRELATION COEFFICIENTS FROM LASL ANTHROPOMETRIC SURVEY

Measurement No.[b]	2	3	4	5	11	13	14	16	17	18
2	—	0.867	0.825	0.113	0.691	—	0.311	—	—	—
3	—	—	0.842	0.052	0.713	0.232	0.236	0.191	0.356	0.449
4	—	—	—	0.040	0.779	—	0.218	—	—	—
5	—	—	—	—	0.057	0.269	0.287	0.324	0.324	0.306
6	—	0.021	—	0.553	—	—	0.277	—	—	—
7	—	0.321	—	0.151	—	—	0.215	—	—	—
8	—	0.189	—	0.124	—	—	0.082	—	—	—
9	—	0.006	—	0.363	—	—	0.262	—	—	—
10	—	0.519	—	0.053	—	—	0.050	—	—	—
11	—	—	—	—	—	—	0.122	—	—	—
12	—	0.153	—	0.090	—	—	0.110	—	—	—
13	—	—	—	—	—	—	0.634	0.615	—	—
14	—	—	—	—	—	—	—	0.616	0.530	0.595
15	—	0.211	—	0.251	—	—	0.834	—	—	—
16	—	—	—	—	—	—	—	—	—	—
17	—	—	—	—	—	—	—	—	—	0.676
18	—	—	—	—	—	—	—	—	—	—
19	—	0.522	—	0.363	—	—	0.612	—	—	0.862
20	—	0.203	—	0.188	—	—	0.457	0.725	—	—

[a]Listed are coefficients greater than 0.6. For face length, face width, and lip length, all coefficients are shown.

[b]
2. Menton-Glabella Length
3. Menton-Nasal Root Depression Length
4. Menton-Nasal Bridge Length
5. Lip Length
6. Lip Length, Smiling
7. Nasal Bridge Breadth, Maximum
8. Nasal Bridge Breadth, Minimum
9. Nose Breadth
10. Nose Length
11. Anterior Chin Projection-Nasal Bridge Length
12. Horizontal Nose Protrusion
13. Maximum Frontal Breadth
14. Bizygomatic Breadth
15. Bitragion Breadth
16. Bitragion-Minimum Frontal Arc
17. Bitragion-Submandibular Arc
18. Bizygomatic-Submandibular Arc
19. Bizygomatic-Menton Arc
20. Bizygomatic-Minimum Frontal Arc

*Excerpt from Ref. 6, pp. 346, 1082.