RECOMMENDATIONS CONCERNING THE ROLE OF WORKPLACE TESTING OF RESPIRATORS AS A CONDITION OF CERTIFICATION

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Report on Prerulemaking Conference on NIOSH Assessment of Performance Levels for Industrial Respirators and Recommendations Based Thereon

Appalachian Laboratory
for Occupational Safety and Health
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CONTENTS

Appendices

1. COMMITMENT

This report discharges the writer's responsibility to meet the requirements of task 4 set out in the Scope of Work attached to Order OMB-No. 0990-0115 provided by NIOSH.

The tasks enumerated in the Scope of Work were:

1. To review the Notice of Proposed Rulemaking (NPRM) for certification of respiratory protective devices published on August 27, 1987, as it relates to workplace performance testing as a condition of certification, and relevant letters and statements that followed publication.

2. To review a confidential draft of the second NPRM.

3. To attend a prerulemaking Technical Conference on the NIOSH Assessment of Performance Levels for Industrial Respirators at Morgantown WV on January 9-11, 1990, and to gather information.

4. To submit written draft recommendations to NIOSH within 45 days of that meeting on:
   4.1 the role of workplace performance testing in the certification program
   4.2 related technical knowledge gaps, research and/or developments needed

5. To present these recommendations informally to NIOSH staff at an agreed time within 90 days of the public meeting.

6. To submit, within a further 30 days, a final report of recommendations with supporting rationale to NIOSH.

June 1, 1991 R. J. Sherwood.

2. EXECUTIVE SUMMARY

1. Having reviewed all relevant literature, including that provided by NIOSH for the assessment, having attended the Prerulemaking Technical Conference and having considered the present status of respiratory protective equipment, this assessor considers that introduction of workplace, or simulated workplace, testing to determine workplace protection factors into the requirements for certification of industrial respirators, used in mines or elsewhere, would be premature. Present evidence indicates that such testing will not provide a realistic measure of the protection provided by negative pressure respirators until major advances have been made in achieving more dependable facepiece fit.
2. The main reason for this opinion is the great variability in protection demonstrated to date in workplace test programs and in fit testing. The uncertainty of extrapolating from any test program to the routine use of respirators is too great to be acceptable..
3. Attention should now be directed to the primary need to know the exposure of workers whilst using respirators. At present, exposure is predicted by applying an assumed protection factor to measurements of unprotected exposure. This cannot be regarded as an adequate method for control of workers' health or life.
4. Any requirement to wear respiratory protection should include an obligation to assess the wearer's exposure. The present uncertainty in the protection achieved, as indicated by variability of protection factor both between individual workers and between occasions of use, calls for a monitoring program at least as stringent as that demanded where protection is not required. Further, neglect of correct respirator usage in the field nullifies any program of facepiece fit testing. The most urgent current research need is to establish a definitive method for determining exposure when RPE is in use. Later, this might be applied to the testing of respirators for certification purposes, but this should not be an initial priority.
5. Approaches to this need are discussed in the text, taking into account work reported since the Technical Conference, as well as the possible development of this assessor's breath sampling respirator, coupled to the sampling respirator described by Luxon.
6. The assessor has seen little progress in performance of negative pressure high efficiency filter respirators since 1962, when he proposed a development objective to achieve a protection factor better than 1000 in 999 occasions out of 1000 routine uses. Greater reliability of facepiece fit must be the prime objective of any R&D program. This might be encouraged by the award of a prize to the first manufacturer of a respirator that meets such a specification in use.
7. He is surprised that anthropometric description of human faces is still restricted to two-dimensional models, and is also concerned at the apparent continuing absence of understanding of facepiece fit principles at the working level. Despite the development of a in 1956 of a full facepiece respirator with integral head covering, presentations at the recent AIHC&E continued to show respirators donned over protective head coverings with high risk of penetration at the face seal.
8. Until reliable negative pressure air purifying respirators can be developed, emphasis should be placed on positive pressure systems which meet further certification requirements to ensure that positive pressure is maintained in the breathing zone at all times, including periods of maximum inspiratory flow. If this is not currently feasible, then a pressure sensitive alarm should be developed and fitted to all high-efficiency respirators.
9. The cost effectiveness of any proposed research program should be critically examined and compared with the likely high costs of field testing for certification purposes.
10. There is most urgent need to establish a consensus on assigned protection factors; all agencies and institutes concerned should coordinate work, and encourage international standardization of assigned values, with clear indication of assumptions made in the process and the likely risk associated with assigned values. If this is not possible, then agreement should be sought on publication of the probabilities of given levels of protection not being achieved on individual wearings (for conditions IDLH or for substances having STEL limits) or over a series of wearings (for substances having TWA limits).

3. INTRODUCTION

Little consideration was given to matters of facepiece fit of respirators until after the second World War when wartime development of military respirators was declassified, and there was urgent need to ensure continuing development of personal protective equipment in the nuclear energy industry. The writer is most familiar with UK developments at that time as his operations research team was called on to investigate evidence of plutonium absorption among workers wearing military-type respirators at a processing plant of the UK Atomic Energy Authority.

Until 1960, respirator development in the UK had concentrated on developing high efficiency filter systems rather than assessing the overall effectiveness, but a presentation by H.J.R. Letts of CDE Porton at an open meeting in 1962(4.33) showed that the full-face military used by the British did not always provide effective protection. At the same meeting the team contributed to a review of Atomic Energy Authority Practice(4.33) which recommended as an objective developing a high-efficiency respirator that would ensure a protection factor of 1000 in not less than 999 wearings out of 1000. Subsequently, the team developed a quantitative test for determining protection factor, and equipment that was installed at entry to contaminated areas of processing plant(4.32). Also, thanks to liaison with the pioneer work of Silverman and Burgess in developing the Harvard-AEC powered respirator, a prototype self-contained pressurized blouse was developed(4.31).

Parallel work was undertaken here in the USA on a much larger scale, pioneered by the Los Alamos group. It led to the development and application of routine and research test methods too extensive to be referenced here.

During the ensuing 30 years many tests of respirators have been made in the laboratory and in the workplace, as well as in laboratory simulation of workplace conditions and activities. Based on these studies, a series of standards have been promulgated and established for the use of different classes of respirators.

The present status of these is shown in the table overleaf. The wide variability of performance accepted by the different organizations suggests that uncertainty still exists in defining the performance of industrial protective respirators. Consideration of overseas standards (eg UKHSE, CEN) further extends the range of limits selected by certifying and standards setting authorities.

More detail of legislative aspects is provided in the following section which reviews information provided before the meeting.

4. REVIEW OF INFORMATION PROVIDED BEFORE THE CONFERENCE.

The literature provided in advance of the meeting is too extensive to review in detail. Only key features are summarized here.

4.1 42 CFR Part 84 NIOSH Revision of Tests and Requirements for Certification of Permissibility of Respiratory Protective Devices Used in Mines and Mining; Notice of Proposed Rulemaking (Federal Register, August 27, 1987).

§ 84.31 of the proposed regulations provided guidelines for workplace, or simulated workplace testing.
§ 84.32 set out requirements in detail. In essence, this required manufacturers to provide substantial evidence that the respirator submitted for certification provides a workplace, or simulated workplace, protection factor at least equal to that class of respirator assigned in the proposed regulation, as listed on page 7.

A comparison of proposed assigned protection factors

OSHA 29 CFR Pt 1910 [Docket H049]			Proposed ANSI Z88.2	Revised NRC
ASSIGNED PROTECTION FACTORS **AIR-PURIFYING RESPIRATORS**				
Using Test:	Qualitative	Quantitative		
Full facepiece	10	100	100	50
Half or quarter mask	10	25	10	10
Any mask with low-efficiency filters	5	-		
Powered air purifying - positive pressure:				
Tight fitting:high efficiency filter		250	1000 f.face	1000
,, dust/fume/mist filter		10	50 h-mask	
Loose fitting helmet:				
high efficiency filter			25	1000
with Tyvek face seal		100		
,, with plastic face seal		50		
ATMOSPHERIC SUPPLYING RESPIRATORS				
SCBA, demand		50	10 h-mask 100 f.face	50
,, pressure demand		10,000	1000	10,000
,, ,, (closed circuit)				5,000
Supplied air, negative pressure				
full facepiece		50	100	5
half facepiece		10	10	5
,, pressure demand				
full facepiece		1,000	1000	2000
half facepiece		1,000	50	
Continuous flow, full facepiece		250		2000
,, half facepiece		250		1000
,, hood, helmet		100		1000/2000
Combination full facepiece pressure demand supplied air respirator with auxiliary self-contained air supply		10,000		

Respirator Class					
Air Purifying		**Atmosphere Supplying**			
Negative pressure		Self-contained (SCBA)		Air-line	
full facepiece	50	negative pressure	50	negative pressure:	
half or quarter face	10	positive pressure	10,000	full facepiece	50
with low efficiency filter	5			half facepiece	10
Powered		Combination positive pressure SCBA with air-line		positive pressure:	
tight fitting facepiece	50	half facepiece	1,000	full facepiece	2,000
loose fitting helmet	25	full facepiece	10,000	half facepiece	1,000
				continuous flow:	
				half facepiece	50
				full facepiece	50
				hood or helmet	25

To gain certification, a respirator would have been required to provide workplace, or simulated workplace, protection factors in excess of the assigned value for its class on at least 95% of users.

§ 84.33 provided for certification at higher levels of protection than those specified in § 84.32.

Comments on 1987 proposals for 42 CFR Part 84.
Responses to this proposal came principally from respirator manufacturers, as individual companies, or from the Industrial Safety Equipment Association. Other Federal Agencies, consultants, and respirator users also offered comments. Some were received following public hearings in January, 1988. Forty-five complete or partial letters have been provided with relevant information, but it is understood that in all 271 submissions were received, totalling 4,000 pages.

Among the many issues raised were:
Cost: predicted to be in excess of $700 million per year
Technical feasibility: three orders of magnitude variability of test results
impracticable specifications for organic vapor test
Extrapolation of data: contaminant characteristics, work activity, environmental conditions, worker demographics.
Lack of correlation between workplace and simulated workplace test results
Lack of clarity in the requirements and dual level certification
Lack of defined standards for expertise in testing and confidentiality of test results
Insufficient mines to permit all the testing that will be required
Absence of strictly defined protocol: alternative preference for CEN standards
Self-certification: fabrication of test results by the unscrupulous
Evidence of failure of RPE use programs rather than equipment
Extension of mining requirements to non-mining applications, including firefighting
Designation as major rule requiring full impact regulatory analysis
Unfair to small business
Requirement for recertification after any modification
Statistical weakness of proposed test procedures
Unsuitability of penetrating test aerosol for non-high efficiency filters, and liquid aerosol tests of electrostatic filters
Protection factors to be prescribed by regulatory agencies
Absence of data to substantiate some of the tabulated protection factors
Absence of workplaces with sufficiently high concentrations to test high efficiency respirators
Inappropriateness of facepieces from use of a standard test panel
Proposed test procedures leading to larger, heavier, and less acceptable respirators

4.2 42 CFR Part 84 NIOSH Revision of Tests and Requirements for Certification of Permissibility of Respiratory Protective Devices
Second Notice of Proposed Rulemaking (September 18, 1989).

Relevant changes from the earlier proposals include:

- deletion of workplace or simulated workplace performance testing; viz
  - § 84.31 Guidelines for workplace or simulated workplace testing
  - § 84.32 Workplace or simulated workplace testing by applicant
  - § 84.33 Workplace or simulated workplace testing by applicant; Certification of higher performance level

- increased specification of hardware & statistical data analysis in facepiece seal tests: § 84.232 (e) & (h), and the performance criteria tabulated below:

Maximum allowed face-seal leakage (L_{max}) for respirator facepiece and test filter combinations

Facepiece	Filter used for face-seal test Type I	 Type II	 Type III
Quarter or half	0.15	0.06	0.05
Full	0.10	0.02	0.01

The summary stresses the fundamental difference between assigned protection factors specified in OSHA respirator selection tables, and the above leakage factors recommended by NIOSH.

General changes include:

- deletion of reference to mines
- requirement for NIOSH to verify some manufacturers test results
- procedures for optional upgrade kit certification
- new certification classes for solid only, liquid only, or both solid and liquid particulates
- revised requirements for human subject protection
- and many minor changes in technical and administrative requirements

The rationale for requiring workplace testing of respirators has been set out in the summary of the second notice (pp 22 - 24). The intention to withdraw the earlier proposals is explained by the wish not to delay needlessly the major advances in laboratory performance tests while concensus on on workplace testing is obtained. NIOSH will publish a separate proposal in the future after adequate opportunity for public comment. At some later still, workplace testing is to be incorporated into the principal regulation on respiratory protection.

Comment on Second Notice.
It is this assessor's opinion that greater clarity would be offered by differentiating between standards for performance and those for manufacturing. This has been achieved in recent EEC Directives which clearly separate standardization for purposes of harmonization of trade and those for worker protection. However, they suffer from being prepared by two completely separate groups within the European Commission and should not be taken as a definitive model.

5. REPORT ON CONFERENCE PROCEEDINGS

Most interests in industrial respiratory protection were represented at this meeting which was well organized by Don Campbell, and attended by about 175 persons. Five assessors have been appointed by NIOSH : Rich Duffy (Firefighters), Bill Hinds (UCLA), Harry Ettinger (Los Alamos), Earl Shoub (Consultant) and myself (HSPH). They have the duty to review the meeting and make recommendations for future NIOSH activity in this field with particular respect to Workplace Protection Factors. The terms are outlined under Commitment (Section 1)

Over the three day period, twenty three presentations were made, comprising reports on field investigations, some more fundamental studies, and position papers from respirator manufacturers, either individually or represented by an Industrial Safety Equipment Association group.

Key NIOSH personnel present included: Larry Sparks (Deputy Director NIOSH), Tom Bender (Director of Safety Research) and Al Amendola (Deputy Director and currently heading Division of Respiratory Disease Studies).

In addition to presentations on field work and new developments by NIOSH and OSHA staff members, and by researchers from a number of universities and institutes, members of ISEA made both individual and group presentations. Of unique importance among these was a review of cost experience of workplace determination of respiratory protection factors, and the presentation of a draft performance criteria document.

Discussions during and after presentations elucidated many points, and provided the assessors with a more thorough understanding of the material. Important reference material was provided by NIOSH prior to the meeting and a number of presentations were accompanied with printed material. Many presenters have contributed published work in the past,and this forms a key base for decision making on future policy.

Much of the immediately relevant literature is summarized or referenced in Appendix 1 in which key points from the presentations are summarized. Numbered references in the text indicate the serial number of information in this Appendix. The material listed is by no means exhaustive, and represents only a fraction of the literature published on respiratory protection.

Of some concern must be the release of information on respirator performance, particularly through trade literature and oral presentations, that has not been peer reviewed. It has unfortunately been necessary in this report to give such information much the same weight as more definitive peer-reviewed reports. The shortcomings of this practice are admitted.

6. REVIEW OF PRESENTATIONS AND RELEVANT PUBLICATIONS

Attention is initially given here to the most commonly used form of respiratory protection - the air purifying respirator with negative pressure in the facepiece. Primary consideration is given to elastomeric facepieces as these are commonly required where hazards are significant, and where the consequences of failure are most serious.

In the following review the term "Fit Factor" is generally taken to be identical with the generic term "Protection Factor". This is not strictly true as the latter includes factors additional to facepiece fit, for example exhalation valve slip. However, for properly maintained respirators, leakage between face and facepiece is the major source of reduced effectiveness.

In reviewing the information presented at the meeting, and in considering all published literature on effectiveness of respiratory protective equipment, two major sources of uncertainty can be identified. These are considered here and should be taken into account in all subsequent discussion.

6.1 Averaging of Protection Factors.

Throughout the literature, reference is made to average Protection Factor or Fit Factor without indication of the method of calculation. The uncertainty this induces in interpretation of results is set out in some detail in Appendix 2.

In essence, it is mathematically incorrect to average "Fit Factors" per se; the correct procedure is to determine the average "Penetration" over a series of wearings and from this calculate the average fit factor as its reciprocal. This can be illustrated thus:

$$\frac{1}{2} + \frac{1}{3} \neq \frac{1}{5}$$

The factor is most significant when assessing the effectiveness of high efficiency air purifying respirators which may fail significantly on rare occasions. An example is demonstrated below:

> Assume that on 4 days of a working week a fit factor of 10,000 is achieved and on the other day only 200. What is the average protection over the whole week?
>
> The arithmetic average is $\frac{10{,}000 \times 4 + 200 \times 1}{5} = 8040 \quad .. \quad .. \quad .. \quad .. \quad (1)$
>
> but this is not the protection actually achieved.
>
> The actual protection is largely governed by the low fit-factor on one day:
> Thus, averaging penetration (reciprocal of fit factor):
>
> $$\frac{5}{\frac{4}{10{,}000} + \frac{1}{200}} = \frac{5}{0.0054} = 925 \quad .. \quad .. \quad .. \quad .. \quad (2)$$
>
> From this it can be seen that, in this rather extreme case, the average fit factor would underestimate exposure by a factor of 8.7 .. .. .. (1) ÷ (2)

This can be shown in the results of a study(1.2) on the use of powered air purifying respirators at a secondary lead smelter. Workplace protection factors for the Racal Model AH3 PAPR are shown in Table II of the article. The WPF GM = 205 & GSD = 2.83. Summing the tabulated values shows that the WPF AM = 342, which might erroneously be assumed to be the measure of the average protection factor achieved. If the penetrations at each usage are calculated (the inverse of the respective WPFs), the correct WPF AM = 115. That is, 1/3 the apparent effectiveness derived from averaging WPF's.

6.2 Assumption of the Log-normal Distribution.

The second key issue relates to the assumed validity of log-normal distribution as a means of determining average protection factor. This assessor was involved in the early transfer of this system of interpretation from particle size determination to personal air sampling(4,35), and he notes that the system is often used today without first determining its validity.

Examples of this problem are evident in results of tests under various climatic conditions (3.1) which show protection factors clustering at >10,000, and at 100 or less, with few intervening values. Critical to the significance of long term average exposure to substances with TWA TLV's, REL's or PEL's are the few occasions when a low PF is achieved, and even more critical is the situation where exposure to substances having STEL's can occur, or conditions are immediately dangerous to life or health.

Further, even when proven it does not provide a direct measure of average protection factor, even when this is correctly calculated from average penetration. The index most commonly reported is that of Geometric Mean (GM), which approximates to the Median, that is the value which half the results exceed. This has little significance as a measure of average effectiveness which is indicated by the Arithmetic Mean (AM) of a series of measurements of protection factor over a number of usages.

A valuable function of the application of this distribution is the ability to determine a Geometric Standard Deviation (GSD) which is a measure of spread, and which enables the probability of any given value occurring to be calculated; most commonly the 5 percentile is selected as an index of acceptable protection. It should however be noted that at this level of protection will not be achieved on some 10 days in a working year, and may therefore incur significant hazard to the wearer, particularly for substances or conditions defined above.

In the absence of a reported arithmetic mean protection factor, it can be calculated from reported GM and GSD, and this has been applied in the following discussion. But it should be noted that it incurs a further measure of uncertainty, additional to that described in the previous sub-section, as it assumes that results can be accurately described in terms of the log-normal distribution.

The possibly misleading effect of interpreting results based on the assumption of log-normal distribution is illustrated in Appendix 3, in which the apparent effect of sample loading on measurements is considered. The following table is taken from that Appendix:

Sample loading X Field Blank	N	GM	GSD	5%	AM
10X	37	2143	3.6	259	4870
200X	32	2340	3.5	324	5130
400X	28	3135	2.5	673	4770
600X	22	4150	2.2	1167	5660
1000x	17	4076	2.3	1038	5770
1200X	15	4023	2.2	1096	5489

The final column of AM is calculated from the equation in Appendix 3.

It would appear that the reported dependence of protection factor on the loading of the in-mask sample may be largely an artifact arising from use of Geometric Mean as a measure of average protection factor. Calculated Arithmetic Mean (last column above) does not appear so dependent on sample filter loading. The evident dependence of GM on loading appears to arise from higher GSD's at low loading values. The cause of this merits more consideration.

The calculation in Appendix 3 relies on an approximation of AM from reported data; this question can only be resolved by reference to the original data obtained from the cited work.

An additional possible cause of indeterminacy of protection factors at low sample filter loadings that has not been fully evaluated is whether the samples are representative of the aerosol cloud. In the past the problem of unrepresentative samples has been limited to radioactive aerosols(4.35), but with the greatly increased sensitivity of PIXE techniques of analysis, detection of only one, or a few, particles on a filter, is possible. These cannot truly represent the cloud sampled. It should be borne in mind that a single 10 µm spherical particle of lead oxide has a mass of about 5 ng, while the limit of sensitivity of PIXE analysis is about 10 ng. A further cause of uncertainty when assessing high-efficiency respirators is the possible contribution of aerosols generated by the wearer to the in-mask sample(4.36).

All the information on results of measurements of protection factor obtained for this report is summarized in a series of tables in Appendix 4, classified by respirator type. Due to the shortcomings already outlined it has not been practicable to analyze the information with adequate statistical confidence.

This can be demonstrated with an example. Analysis of data on elastomeric half face respirators provides the following results:

Number of observations = 19
Calculated GM = 651.5
Calculated GSD = 9.21
Calculated $AM_{(s)}$ = 3132
Calculated $AM_{(pf)}$ = 7638
Calculated $AM_{(p)}$ = 55

where:

AM for each operation has been calculated from the equation in Appendix 3.
$AM_{(s)}$ is the sum of the calculated AM for each operation monitored.
$AM_{(pf)}$ is calculated from $AM_{(s)}$ of each operation as above
$AM_{(p)}$ is the reciprocal of the mean penetration calculated for each operation.

From scanning the table it is apparent that the value of 55 calculated from $AM_{(p)}$ is the most likely best estimate, but this includes a large error of uncertainty as it is not known how the tabulated values of GM have been calculated.

In the circumstances, no firm conclusions can be drawn from the data, other than that elastomeric half-facepiece respirators provide a highly variable protection factor. The critical issue is represented by the very high value of GSD shown in some trials, not only in workplace testing, but also in quantitative fit testing and work simulation studies (GSD up to 9).

When further allowance is made for the variability of concentrations of workplace air contaminants in time and space (GSD 2-5), and noting that the two GSD's should be multiplied to determine overall variability of exposure when respirators are worn, it is apparent that the development of reliable protection factors for negative pressure respirators is unfeasible, and that research efforts could be better directed elsewhere - primarily in designing facepieces which can provide reliable protection through assured standards of fit.

Consideration may be given to the feasibility of determining protection factor every time a respirator is worn. Although this has been undertaken in the past where significant hazards exist it is certainly not universally practicable and, if present methods of quantitative fit testing are employed, it would require provision of a sampling point on each mask with concomitant risk of failure to seal during work exposure (but see Section 6.3 on new techniques).

Test results reported(1.2) indicate that no correlation was found between WPF's achieved with PAPR's and Fit Factors quantitatively determined immediately prior to use. WPF's were in the range 30-5,000, whereas Fit Factors were in the range 1,200-31,000.

Arithmetic means of fit factor averaged 30-40x that of WPF, and, though not of great mathematical significance, indicate serious overestimation of workplace effectiveness. Another presentation(1.13) also concluded that, for half-face filter respirators used for protection against lead, quantitative fit tests were not dependable as quantitative predictors of WPF. Even when the quantitative fit testing was undertaken during an exercise routine before the workers removed respirators following work, no correlation between WPF and simulated WPF was reported (2.2).

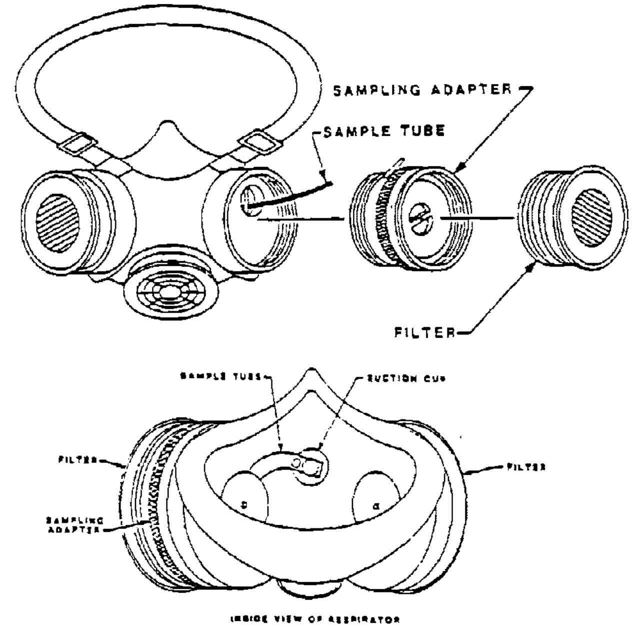
Further it is very evident from the reports referenced that conditions of work have a marked influence on protection factor achieved. This is perhaps most clearly demonstrated in the tabulated results on powered air-purifying respirators. Whereas in pharmaceuticals, PF's of 10,000 are achievable, in lead work typical values are in the range 100-400, and in uranium mining only 5-20 is reported. Significant differences in performance between masks and helmets may complicate this interpretation.

It may also be evident from the greater WPF achieved in paint spraying than in foundry work(2.6,2.7), though it was suggested that detection of odor when a respirator is being worn provides immediate warning of inadequate protection.

6.3 New Techniques for Testing Negative Pressure Respirators.

The reported studies indicate clearly that the sampling of air from within facepieces does not necessarily provide a reliable measure of exposure of the wearer. Accuracy is critically dependent on the relationship of sampling position in the facepiece and the location of the leakage at the face to mask seal(2.18 & 3.6).

Subsequent to the technical meeting a new system for sampling air inside a facepiece has been reported which obviates the need to fit a sampling port(4.39). As it does not infringe any certification requirement it can presumably be used to estimate the exposure of a person wearing a respirator at work. This is a fundamental requirement and priority should be given to the determination of the method's accuracy.



The TSI Inside Mask Sampling Adaptor

A further uncertainty arises when sampling from within the respirator throughout the breathing cycle as loss due to deposition in the respiratory tract cannot be readily determined. Theoretical aspects of this were considered(2.3), taking into account the size distribution of particles known to penetrate facepiece seals and depositing in the lungs. It is rather ironic that the information required when respirators are worn (that is the amount of hazardous air contaminant retained by the respirator user) has come to be regarded as an undeterminable variable in the testing of respirators for certification.

To overcome problems of uneven distribution of air contaminants inside masks, and to avoid the need for modification of facepieces to collect in-mask samples, Crutchfield reported two new methods for quantitative fit testing of respirators. In one method(3.2,3.4), filters are replaced by diaphragms and a known negative pressure established inside the facepiece while the wearer holds his breath; leakage is then directly measured by a sensitive technique. This method restricts selection of an exercising routine, and can provide only an "instantaneous" measurement.

The second method(3.3) employs a completely new approach to fit testing and depends on the measurement of Freon 113 in exhaled breath 30 minutes after a standard exposure to that substance. Individuals are calibrated by means of a dilute vapor cloud. The technique is at a very preliminary stage of development.

The negative pressure method(3.2) indicated fit factors between 6 and 50% of those determined by quantitative aerosol tests, though the difference averaged only 37% when fixed leaks were introduced(3.4). The breath analysis method indicated leakages about 2.5 times those determined from negative pressure testing(3.3).

6.4 Use of Positive Pressure Respirators

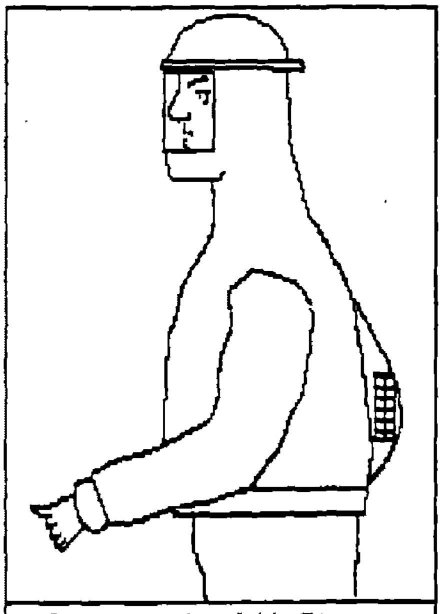
The only reliable systems that offer warranted protection at this time are those providing a positive pressure at the face throughout the breathing cycle. These types are represented by PAPR's, positive pressure demand SCBA, or airline respirators.

To achieve this, a positive pressure must be maintained at peak flow, which may reach >100 L/min when a subject is working hard - as in firefighting.

PAPR systems involving helmet configurations are particularly vulnerable to inflow at the periphery of the facepiece. Outward flow must be sufficient not only to meet peak respiratory inflow but also to overcome draught generated by environmental conditions (ie wind in outdoor operations, ventilation air movement in mining operations), and by body and head movements which may create significant disturbance.

One method of obviating this is to enclose the chest as well as the head in the containing system so that rapid intake of breath is matched by rapid expansion of the chest volume. In these conditions positive pressure need be maintained only at considerably lower flow rates.

A prototype self-contained air blouse was demonstrated by the writer in 1965(4.31); the keys to further development lie in the better distribution of air within the headpiece to minimize rebreathing of CO_2, and provision of an adequate supply of air for escape purposes.



Self-contained Air Blouse

One presentation stressed the problem of finding workplaces where testing could be undertaken. Although extensive workplace studies have been made in the past, it is increasingly difficult to find representative locations, and, indeed, each workplace may only be representative of itself at the time of testing. A critical factor, that is increasingly evident from the presentations on the performance of high-efficiency negative pressure respirators, is that an effective seal is usually established during many usages, but serious penetration can occur on rare occasions. This characteristic dictates the need of long term test programs to assess average exposure and the frequency of failure to achieve an acceptable standard.

A major obstacle that cannot readily be resolved is the considerable cost of tests as reported by manufacturers and its contribution to final cost of products, even if generic testing is permitted. Any requirement for definitive evaluation of protection factor for all types of respirator might well restrict future suppliers to a few adequately capitalized major manufacturers, and would certainly inhibit the further development of respirators that is urgently needed. This problem will remain even if a satisfactory testing protocol can be developed.

Simulation of workplace testing appears to offer little guidance on the effectiveness of respirators in the workplace itself due to the very high variability of exposure, of the protection factor achieved, and of the work itself. Simulated testing for all conditions would be excessively expensive and time consuming. It would continue to require the application of some "guesstimated safety factor" when used to select suitable equipment for routine and less supervised use in the workplace.

The present wide variation in assigned protection factors published by regulatory and standards organizations, while it indicates the great uncertainty in protection achieved by respirators, must generate even greater uncertainty in the minds of those directing respiratory protection programs. As a matter of urgency, common standards should be agreed and promulgated. If this is impracticable then agreed standards should be published indicating the probabilities of given levels of protection <u>not</u> being achieved on individual wearings (for conditions IDLH or for substances having STEL limits), or over a series of wearings (for substances having TWA limits).

7. CONCLUSIONS

At the present time techniques for assessing effective protection factors are not sufficiently developed to permit reliable prediction of performance from laboratory, simulated workplace or workplace studies.

Until more consistent performance of negative pressure respirators can be achieved, even improved technology cannot provide definitive indication of effective performance of respiratory protective equipment.

The very extensive program of work already undertaken should not be rejected but continue to be used as a basis for consensus testing standards. It must be recognized that the large margin of likely error may be unacceptable to legislators, and that too extensive a safety margin will preclude many respirators that are acceptable to those requiring protection. A factor of 10 appears to be a reasonable factor to select on the basis of past experience, but it must be accepted that it carries a significant element of risk - particularly where exposure is to substances assigned a ceiling or short term exposure limit, or where the atmosphere is immediately dangerous to life or health.

In this context, the proposal by Howie(2.5) to categorize factors affecting efficiency in broad general terms might offer a reasonable compromise solution and merits attention.

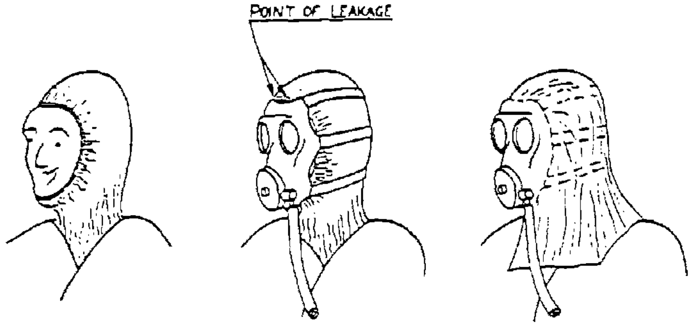
At this time rather facile assumptions are sometimes made in the interpretation of experimental results, the strictest statistical control of experimental programs is essential. Based on the assumption of the log-normal distribution of results, a 5 percentile level of achieved protection appears to be taken as an adequate margin of safety. This is too low an order of acceptable risk; the immediate objective should be 0.1 percentile, though this further calls into question the validity of the log-normal assumption.

Although not deriving directly from presentations at this meeting, it must be recognized that all testing programs introduce a measure of unrealism into protective practice. Only where very significant hazards are recognized is it likely that the same level of protection will be achieved in routine work as is determined in certification testing, and even there allowance must be made for some deterioration in performance with use. In extreme cases, workers have been known to deliberately interfere with respirator components to obtain greater comfort in use (eg by removing the exhalation valve).

An important aspect not considered at the meeting is the reliability of exhalation valves (4.37). Improved design is necessary to reduce the risk of failure or slippage, and particularly to prevent the penetration of air contaminants (eg paint) that may interfere with its proper seating.

There are evident shortcomings in the use of a two-dimensional matrix for selecting subjects for test panels. Better definition of anthropometric factors affecting facepiece seal is required. The objective must be to develop respirators which can provide a more consistent standard of fit, rather than those that can provide an even higher standard of protection - but not consistently.

Education of managements on the fundamentals of respiratory protection, on meeting their responsibilities, and in implementing programs, is most urgently needed. This requires a follow through in the training supervisors and workers. The need for this was clearly seen in presentations at the recent AIHC&E where illustrations of hazardous waste site operations showed respirators donned over protective head coverings, with high risk of penetration at the face seal. The integral head covering developed in 1956 for the full-face respirator is still not standard personal protective equipment, even though it was further developed in the 1960's with a double-skirt head covering for use in radioactive emergency situations.



COTTON HELMET. TUCKED INSIDE OVERALLS

RESPIRATOR OVER COTTON HELMET

IMPROVED RESPIRATOR. RUBBER HEAD COVERING ATTACHED TO FACE-PIECE. WORN OUTSIDE OVERALLS

From A Lead Hazard in Boiler Cleaning, R.J. Sherwood,
AMA Arch. Indust. Health, 14. 92-95, 1956.(4.34)

8. RECOMMENDATIONS

1. Extensive research into workplace simulation of use of respiratory protective equipment should be discontinued as it is unrealistic at the present stage of respirator technology, and is unlikely to be cost effective.

2. Manufacturers of respiratory equipment should be encouraged to improve the reliability of their equipment. Until more consistent performance can be ensured, simulation testing cannot be depended on to give a reliable measure of protection achieved in the workplace. The design objective for a high-efficiency respirator proposed in 1962 remains valid:

   a protection factor of 1000 should be achieved on 999 out 1000 uses.

3. Statistical methods of interpreting test results, and of actual protection factors achieved in the use of respiratory protection, must be critically reviewed. In particular the validity of assuming the log normal distribution must always be tested, and clear indication of the basis used for averaging reported protection factors should be given in all publications.

4. Positive pressure protective equipment must have adequate performance to maintain positive pressure during maximum inspiratory flow even when the wearer is working hard. This requirement should be numerically specified in any certification program. An example is given in British Standard 4667:Pt 2 (1974)(4.39) which requires that:

   > The demand valve shall operate such that the minimum mask cavity pressure shall be not less than that indicated by a straight line joining a value of 10 mm H_2O at zero flow to a value of 0 mm H_2O at a flow of 250 l/min at all cylinder pressures above $5000 kN/m^2$, when tested in accordance with Appendix D.

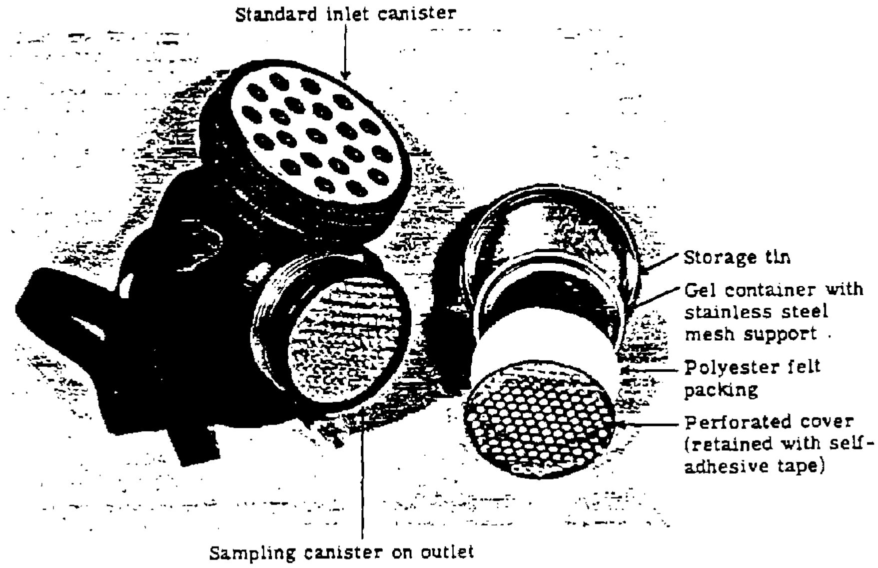
5. Although most development work should now concentrate on control methods that do not require personal protection to be used, work in this field should concentrate first on the largely unknown area of determining actual exposure during respirator usage. Research should initially concentrate on developing a dependable and unobtrusive method of monitoring exposure of workers while wearing respiratory protective equipment. It appears anomalous that, at present, personal air sampling is commonly required where unprotected workers may be exposed to air contaminants, yet exposure of workers wearing respirators is at best estimated from guesses of likely protection achieved, supported in a few cases by biological monitoring programs (eg for lead).

6. This assessor's opinion is that the most productive research at this time would be to study the feasibility and reliability of assessing exposure by sampling air within the respirator by the TSI sampling adaptor, or by determining the concentration in air exhaled from the respirator. The advantages of the latter approach include:
   - .1 losses due to deposition of particles in the respiratory tract, or vapor absorbed by the system, can be estimated with reasonable accuracy compared with variable errors arising from the location of any sampling point within the facepiece.
   - .2 the volume of air exhaled is greater than sampled by personal air sampler so sensitivity is enhanced.
   - .3 modern filtration and adsorption media should create little resistance to flow and no additional power source or sampler need be carried.

   The principal disadvantage of such a system is that exhalation valves may not be tested, though this would be dependent on the fitting of the test cartridge.

   The advantage of the former is that it probably does not nullify NIOSH certification of any elastomeric respirator; the disadvantage may be the uncertain representativeness of the concentration of the contaminant inhaled.

7. A basis for an exhaled breath sampling system is to be found in the breath sampling respirator illustrated below. This would be used to determine the total quantity exhaled. To determine the concentration, a flow measuring device similar to that also shown below may be incorporated. Both systems would require development and testing programs.



From: The Measurement of Occupational Exposure to Benzene,
R.J. Sherwood & F.W.G. Carter, Ann. Occup. Hyg., 13, 125-146, 1970.

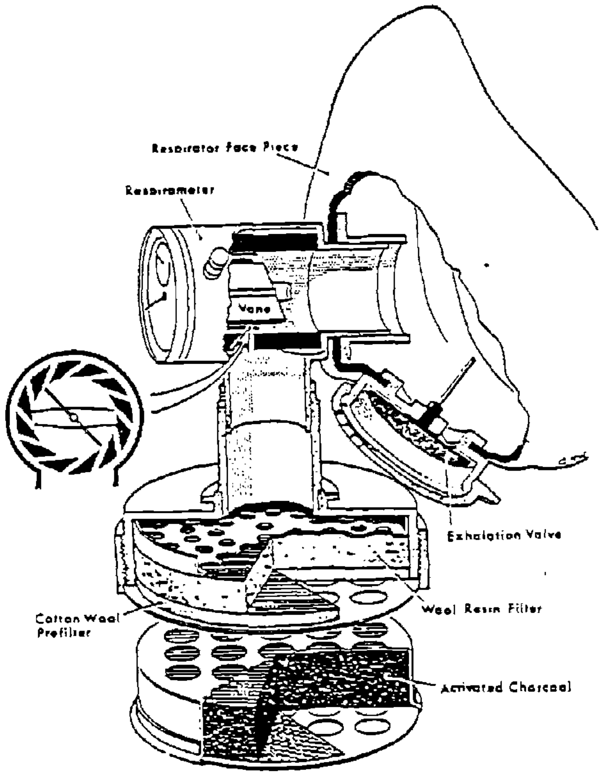


Fig. 2.

From: The Use of Respiratory Devices for Evaluating Environmental Hazards,
S.G.Luxon, Ann. Occup. Hyg. 9 15-21, 1966.

APPENDIX 1

NIOSH RESPIRATOR WORKPLACE PROTECTION FACTORS

SECTION 1. GENERAL REFERENCE MATERIAL

1.1 Performance Measurements on a Powered Air Purifying Respirator Made During Actual Field Use in A Silica Bagging Operation.

Warren R. Myers & Michael J. Peach,III (NIOSH), Ann. Occup. Hyg. 27, 3, 251-259, 1983.

Measured Protection Factors		
1/2 face	42,87,193,16,67,49,19	N = 7 AM = 68 Plot: GM =
60 GSD = 2.5		
Fullface	25,54,215, -	N = 3 AM = 98

1.2 Workplace Protection Factor Measurements on Powered Air Purifying Respirator Made at a Secondary Lead Smelter: Results and Discussion.

W. R. Myers, M. J. Peach,III, K. Cutright and W. Iskander, Am. Ind. Hyg. Assoc.J. 45, 10, 681-688, 1984

Measured workplace protection factors					Pre-shift quantitative fit factors		
	N	Range	GM	GSD	Range	GM	GSD
Racal AH3	24	42-2323	205	2.83	2000-31,500	7900	2.5
3M W-344	24	28-5500	165	3.57	1200-24,600	5100	2.4
Combined data			6200	2.48			

Ratio: quantitative fit factor ÷ workplace protection factor (each use)

	Range	GM
Racal AH3	3.6-256	38.5
3M W-344	1.2-304	30.9

% of variation inside facepiece dependent on outside concentration

Racal AH3	23
3M W-344	none

1.3 Field Test of Powered Air Purifying Respirators at a Battery Manufacturing Facility.

W. R. Myers, M. J. Peach,III, K. Cutright and W. Iskander, Journal ISRP 4, 1 62-87, 1986.

Measured workplace protection factors for lead					
	N	Range	GM	GSD	5%ile
Racal AH5	24	23-1063	120	2.64	
3M W-316	22	31- 392	135	1.89	
Combined data	46	31-1063	127	2.28	25

1.4 Assigned Protection Factors for Two Respirator Types Based upon Workplace Performance Testing.

S.W. Lenhart and D.L. Campbell, Ann.Occup. Hyg. 28, 2, 173-182, 1984.

Primary Lead Smelter: workplace protection factors						
	N	Range	GM	GSD	5%ile	APF 5%ile with 90% confidence
MSA half-mask						
negative pressure	25	10-2200	180	4.1	18	10
powered	25	23-1600	380	2.6	79	50

1.5 Workplace Protection Factor Study for Airborne Metal Dusts.

A.R. Johnston & H.E. Mullins. 3M. Paper presented at AIHA Conference Montreal, 1987.

1/2 face disposable respirators with dust/mist filters PF's at polishing, & grinding operations				
Substance	N	GM	GSD	5%ile
Al	10	145	2.3	32
Ti	14	59	1.7	24
Si	14	172	3.1	24

1.6 Workplace Protection Factors for a Powered Air Purifying Respirator.

C.E. Colton, H.E. Mullins & C.R. Rhoe. 3M, AIHA Conference Orlando. 1990.

3M W 3205 Whitecap Powered Air Purifying respirator with 3M 7800 full facepiece and W3210 high efficiency filter. Measured at a secondary lead smelter:

Substance	N	GM	GSD	5%
Pb	20	4226	2.9	728

>50% measurements rejected here as internal below limit of sensitivity, variation with loading

1.7 Workplace Protection Factor Study on a Half-Mask Dust/Mist Respirator.

C.E. Colton, A.R. Johnston, H.E. Mullins & C.R. Rhoe. Poster session at AIHC Orlando, 1990.

3M 9906 Dust/Mist Respirator, at an aluminium smelter (outside sample respirable dust):

Substance	N	GM	GSD	5%
Al	23	27	1.5	13

1.8 Workplace Protection Factor Study on a Full Facepiece Respirator.

C.E. Colton, A.R. Johnston, H.E. Mullins & C.R. Rhoe, Paper for presentation at AIHC St. Louis 1989.

3M 7800 Full Facepiece respirator with 7255 high efficiency filters & 7288 filter retainers. Measured at a secondary lead smelter:

Substance	N	GM	GSD	5%
Pb	20	3929	9.6	95

Sensitivity limit related to particle size? (see paragraph 2, page 12)

1.9 Workplace Protection Factor Study on a Half Mask Respirator in a Brass Foundry

C.E. Colton, H.E. Mullins & C.R. Rhoe, Paper for presentation at AIHC Orlando 1990.

3M 9970 High Efficiency Respirator, measured at a brass foundry

Substance	N	GM	GSD	5%
Pb*	43	310	4.3	28
Zn	62	681	5.6	40

* 20 internal samples below detection limit

1.10 Workplace Protection Factor Study on a Supplied Air Respirator.

A.R. Johnston, C.E. Colton, D.W. Stokes, H.E. Mullins & C.R. Rhoe, Presented at AIHC St Louis 1989.

3M W-8000 Whitecap II General Purpose Helmet + various trimmings, grinding operations at a foundry

Element	X̄ Field Blank	N	GM	GSD	5%	Element	X̄ Fld. Blk.	N	GM	GSD	5%
Fe	>25	39	273	5.7	39	Si	> 10	32	220	5.3	14
	>100	30	518	4.2	50		> 25	24	360	4.6	29
	>200	24	612	3.9	64		> 50	18	482	3.1	75
	>300	15	770	3.0	125		>100	14	904	2.6	186
	>500	12	837	3.4	110		>200	10	1142	3.0	187
	>750	8	1012	2.6	199		>300	8	1417	3.0	224

Regressions: Fe Log WPF = 1.23 + 0.78 log outside filter weight $r^2 = 91\%$
Si Log WPF = 0.94 + 1.09 log outside filter weight $r^2 = 99.4\%$

Respirator Workplace Protection Factor Studies

- 1.11 Powered Air Loose-fitting Helmet.

D.W. Stokes, A.R. Johnston, and H.E. Mullins, 3M

3M Airhats Dust exposure at roofing granule production						
	Substance	X̄ Field Blank	N	GM	GSD	5%
dust/mist with shroud	Si	25	18	11800	3.1	1615
dust/mist without shroud			27	877	5.2	53
HEPA			12	5370	3.0	762
dust/mist with shroud		100	16	11500	3.2	1484
dust/mist without shroud			26	915	5.3	54
HEPA			11	5542	2.9	877

- 1.12 Supplied Air Abrasive Blasting Helmet.

Using silica sand to blast paint from a barge top 3M Model W-8100 Whitecap II abrasive blasting helmets					
Substance	X̄ Field Blank	N	GM	GSD	5%
Respirable dust	500	8	3600	1.9	1154 (minimum flow 6.7 cfm)
		5	4800	2.4	916 (maximum flow 14.4 cfm)
		13	4023	2.1	1096 (total)

1.13 Workplace Protection factors for Negative Pressure Half-mask Facepiece Respirators,

Stephen W. Dixon and Thomas J. Nelson, Journal of ISRP, 2, 4, 347-361, 1984.

Measured workplace protection factors					Pre-shift quantitative fit factors		
	N	Range	GM	GSD	Range	GM	GSD
Survivair 2000	37	94->27,000	3400	3.8	350-1750	1000	≈2
(including those when worker broke seal to talk:					Pre & post shift quantitative fit factors		
		40->27,000	2400	5.1	35-4460	750	≈2

Air lead concentrations and blood lead were compared with workers wearing MSA Comfo II half-masks in dusty areas. No correlation was found, but mean blood levels ≤ 30 µg/100 g.

1.14 Workplace Evaluation of a Disposable Respirator in a Dusty Environment,
Laurence D. Reed, Steven W. Lenart, Richard L. Stephenson & Joan R. Allender, Appl. Ind.Hyg. 2, 2, 53-56, 1987

Measured workplace protection factors:					
	N	Range	GM	GSD	5%ile
3M 9910	19	1.6-150	18	3.1	2.5

1.15 Program Protection Factor Study on the 3M W 316 Airhat.
S.W. Dixon, T.J. Nelson and J.E. Wright, presented at AIHC, Detroit, 1984.

Measured program protection factors:					Pre-shift quantitative fit factors			
	N	Range	GM	GSD		Range	GM	GSD
3M W 316 Airhat	46?	37->1500	230	3.0	Standard	3,500-260,000	77,000	4.5
					4 mph walk	250- 79,000	8,700	10.0

1.16 Respirator Workplace Protection Factors for Asbestos - Parts 1 and 2.
Stephen W. Dixon and Thomas J. Nelson Presented at AIHC Las Vegas, 1985.

Measured workplace protection factors					
	N	Range	GM	GSD	5%ile
3M 8710	16	7.4-3200	310	5.3	20
3M 9910	14	94 -5600	580	4.2	55
AO R1050	7	9.7-970	52	4.2	5
Survivair 2000 or MSA Comfo II with dust, fume & mist filters:					
	17	15-4200	240	6.3	12
with high efficiency filters:					
	14	12-7900(outlyer)	94	3	16
North 7700 with high efficiency filters:					
	14	12-3100	250	6.9	11

1.17 Field Protection Factors for an Air-Supplied Respirator,
K.L. White, J. Lee, A. DeVito, A. Humfeld, J. Loomis, R. Marcinko, B. Craft.

Measured workplace protection factor Racal AH3 & AH5					
	N	Range	GM	GSD	5%ile
Foundry dust	22	2.8-97.2	21.0	3.30	3
Lead dust	30	2.1-97.9	11.6	2.72?	2.5
Mine dust	34	1.83-98.17			
Shear operator		) approx.	17	3	3.2
Jack setter		) values	10	2.3	2.7
Tailgate operator		) only	8	2.4	2.1

1.18 Workplace Protection Factors of Powered, Air-purifying Respirators,
D.R. Keys, H.P. Guy, and M. Axon. Paper for presentation at AIHC Orlando 1990.

Measured workplace protection factors for pharmaceuticals					
	N	Range	GM	GSD	5%ile
Racal Breatheasy 10	29	1150- 304,000	11,137	3.9	1,197
Bullard Quantum	9	1230- 62,700	9,574	3.1	1,470
3M Whitecap II	22	1810-4,700,000	42,260	9.8	997

1.19 Study of Efficiency and Current Use of Respiratory Protective Devices.

S.H. Linauskas and F. Kalos, Research Report for Atomic Energy Control Board of Canada.

Measured workplace protection factors of PAPR Racal AH-5. for radon daughters in a uranium mine					
	N	Range	GM	GSD	5%ile
with new filters	59	1.0-64.3	17.8	1.84	(6.8)
after 4 days' use	30	1.3-16.3	5.3	1.79	(2.0)

1.20 Workplace Protection Factor Study of Particulate Half-Facepiece Negative Pressure Respirators at Two Lead-Acid Battery Manufacturing Facilities

Barry G. Pallay and John F.Gamble, NIOSH. (Draft)

Measured workplace protection factors for lead					
	N	Range	GM	GSD	5%ile
unknown	214		204	3.56	25
in mask concentration					
measurable	160	2-2739			
below LOD	59	38-4965			

Paper includes review of all published WPF's and discusses effects of many factors

1.21 Determining and validating the Adequacy of Air-purifying Respirators used in Industry. Part 1 Evaluating the Performance of a Disposable Respirator for Protection Against Mercury Vapor.

Howard J. Cohen, Journal of the ISRP, <u>2</u>, 3, 296-304, 1984

Prototype respirator tested in caustic chlorine plant.

Measured workplace protection factors for mercury, corrected for lung retention & previous exposure				
N	Range	GM	GSD	5%ile
26	7-567	41	≈2.9	≈7

1.22 Variability in Protection Afforded by Half-mask Respirators against Styrene Exposure in the Field.

Kit Galvin, Steve Selvin & Robert C. Spear, Am. Indust. Hyg. Assoc. J. <u>51</u>, 12, 625-631, 1990.

Authors express results as penetration:

North Model 7709 with N7500-1 organic vapor cartridges.				
	N	Range	GM	GSD
Sprayers	28	2.8- 588	67	
Non-sprayers	35	6.7-1000	91	
Combined	63		79	3.51? between individuals 1.91 within individuals 2.93

1.23 A Practical Field Method for Measuring the Effectiveness of Intermittent Respirator Usage.

R.S. Larsen, Indust. Hyg. Forum, Am.Indust.Hyg.Assoc.J. 47, A 775-776, 1986

Used organic vapor monitor (3M Series 3500 inside and outside 3M; Norton and MSA organic vapor half-masks during various operations with different solvents.

Effective protection factor	Respirator use (%)
28.6	50
1.9	75
5.0	66
1.1	33
8.6	20
2.9, 2.4, 1.8	40
6.9, 6.3	85
37.4	100
4.7	40
1.8	15
3.5	50
2.8	50
3.8	25

1.24 Measurement of Protection Factors of Chemical Cartridge, Half-mask Respirators under Working Conditions in a Copper Smelter,

David E. Moore and Thomas J. Smith, Am.Ind. Hyg. Assoc. J. 37, 453-458, August 1976.

Effective protection factor					
	N	Mean	Median	GSD	5%ile*
Type A	26	22.13	15.29	2.31	4.0
Type B	25	18.38	13.72	2.11	4.3
Type C	25	12.88	9.59	2.16	2.5

* scaled off from plot of median & GSD

1.25 Exposure of Firefighters to Toxic Air Contaminants.

Avram Gold, William A. Burgess and Edward V. Clougherty, Am. Ind. Hyg. Assoc.J. 39, 534-539, 1978.

Although no comparisons were made between concentrations inside mask and ambient, the distributions of in-mask concentrations are given for:

Contaminant	GM	GSD	5%ile*
CO (ppm)	110	3.0	700
HCN (ppm)	0.04	8.3	1.3
Particulate (mg/m^3)	21.5	4.7	300

* all percentiles are values scaled off diagrams

1.26 Air Contaminants Encountered by Firefighters.

Robert D. Treitman, William A. Burgess and Avram Gold, Am. Ind. Hyg. Assoc.J. 41, 796-802, 1980.

All results in the following table are scaled off diagrams.

Contaminant	GM	GSD	5%ile
CO* (ppm)	140	3.8	1400
HCN (ppm)	0.13	8	0.41
Particulate (mg/m^3)	27	8.6	860
Acrolein (ppm)	0.43	4.7	4.3
HCl (ppm)	2.0	10	83
NO_2 (ppm)	0.24	4.2	2.4
C_6H_6 (ppm)	0.79	6.3	20
*CO source is the fireman	-	-	-

It is noted that for CO, HCl and Acrolein 95% of the samples reached the IDLH. These results may be compared with reference 2.1 above.

SECTION 2. TECHNICAL PRESENTATIONS AT MEETING

2.1 Project Firesmoke:
A Workplace Evaluation of Self-Contained Breathing Apparatus

Gary P. Noonan, Chief, Protective Equipment Section, NIOSH. See also a draft paper: **Environmental Study of Firefighters, J. Jankovic, W. Jones, J. Burkhart & G. Noonan**. Information is available only from notes taken at meeting and the transcript; no visuals available.

The intention was to study jointly with FEMA (project officer Bob McCarthey) the effectiveness of SCBA required by OSHA Standard 1910.156 when firefighting. Development of equipment and problems in use were described. Early experience showed need for equipment to be switched on only after facepiece is donned. A facepiece pressure recording system was developed and used to demonstrate that negative pressure excursions occurred at high breathing rates (typically 50 breaths/minute). The records also show that firemen break the facepiece seal on occasions, probably by removing the facepiece to communicate. CO in breath samples were taken before and after firefighting; where possible non-smoking firemen were selected for measurements. During firefighting CO samples were collected from ambient air and from inside the facepiece through a sampling point located between the nose and mouth. Samples were taken by low-flow pumps and held in 3-liter insulated Tedlar bags shielded against radiant heat. Multi-component analysis was made by Fourier transform infrared spectrophotometer carried in a support vehicle. Some slides of results were shown on slides but are not available; CO, CO_2, HCN, C_6H_6 were included and inter-compound variation appeared to be less than a factor of 3. Possible outgassing of C_6H_6 from new facepieces was queried but it was confirmed that the mask had been removed on the only occasion that C_6H_6 was significant., and this was at a low energy fire when SCBA was not required. The work is to be published It was reported that the results were similar to those published by Burgess and Silverman years ago.

Lessons learned from study include:

- many basic assumptions proved wrong
- program can settle into a routine
- initiate sampling by pressure switch
- single on-off switch control of whole system
- need for check valves in systems
- value of pressure recording in interpreting WPF's and use of logger to control sampling

The findings of the reports are however limited and subject to uncertainty - particularly with respect to the extent that respirators were worn throughout significant periods of exposure to air contaminants. Also, the data is so presented that it is not possible to identify pairs of samples - that is samples taken simultaneously outside and inside masks being worn. The following table has been roughly estimated from figures in the text with much extrapolation:

Gas	Ambient during knockdown Median ppm	GSD	In mask Median ppm	GSD	PF (of medians)
CO	145	4.7	c.5	4.7	30
Methane*	25	6.1	c.2	4.5	12
Acetaldehyde#	0.7	17	c.0.003	17	c. 230
Formaldehyde	1.5	7.0	c.0.025	3.4	c. 60

* also propylene, ethylene and acetylene (as methane)
\# excessive extrapolation required
CO_2 not relevant as main source in mask is exhaled air.
C_6H_6 identical distributions for ambient and in mask, but data inadequate to analyze.

Uncertainty of this data source is shown by apparent protection factors of 12.5 - 230.

2.2 Workplace Protection Factor Study of Half-Facepiece Particulate Air Purifying Respirators at Two Lead Acid Battery Manufacturing Facilities

Barry G. Pallay, Chemical Engineer, NIOSH.(see 1.20 above).

Presentation considered fundamental issues relating to the studies, such as:
Sampling biases:
- deposition on sampling casette walls. This could be corrected for ambient air samples, but the variation was too great for in-facepiece samples.
- deposition on sampling lines found not significant (<5%)
- non-uniform mixing in facepiece
- low concentrations in facepiece (61 out of 222 samples were below sensitivity limit)
- analytical method errors
- contaminated sampling media
- penetration of casette filter

Importance of particle size on:
- pulmonary deposition
- penetration into facepiece
- deposition on casette wall

Relationships to be considered:
- WPF, EPF, PPF
- WPF/simulated WPF

Significant workplace variables:
- substance evaluated
- brand and model of respirator
- industry, facility, process
- occupation of worker
- work load of worker
- environmental conditions
- particle size distribution

Equipment issues:
- need to heat cassette on facepiece sampler to reduce condensation
- analysis by PIXE
- size analysis by PIXEA International impactors; personal samples by PIXEA Streaker

Other issues:
- lead particle size distribution generally found to be trimodal log normal
- elemental analysis of samples indicated substance-dependent variation of WPF
- suggests that use of area samples for size analysis is sufficiently accurate (<16% error in his studies)

Kev findings:

- whilst still wearing respirators used at work,workers were given 14 exercises using Quantifit instruments in a mobile lab.

  No correlation was found between WPF and stimulated WPF.
- casette wall deposition typically leads to overestimation of WPF by factor of 4
  lung deposition typically leads to overestimate by factor of 1.5.
  so total typically overestimates WPF in his studies by factors of 6 to 8.2.
- discussion revealed that in the fieldwork greater variability was found in a series of measurements of WPF on an individual worker (intra-subject variability), than between one worker and another, but that intra-subject variability also varied widely from worker to worker.

2.3 A Model for Correcting Workplace Protection Factors for Pulmonary Deposition and Other Effects

Paul Hewett, Industrial Hygienist, NIOSH. Paper yet to be published.

This was a mathematically rigorous presentation on corrections to be applied for aerosol losses in facepiece leakage and in lung deposition depending on the size distribution of the ambient aerosol.

A model for deposition of typical in-facepiece aerosols in the lungs of the "Reference Worker" has been developed. Some anomalies exist between notes made of slides and the transcript. But is appears that with a GM of 2.5μm and GSD of 1.5, a correction of only 10% is required. But if the GM was 10μm then a factor of two would be required. This simply assumes completed retention of all particles greater than 10μm.

A number of factors have been considered but no account is taken of particle charge effects which may be critical where filters dependent on static charge used. The term "actual" protection is used in the text; "standardized" might be preferable as the system enables results of actual fit factor measurements to be translated to determination of workplace exposure when concentration and size distribution of the workplace aerosol is known. These factors are probably less significant than the day-to-day and operation-to- operation variability of facepiece fit.

If total retention of particles is assumed, the error cannot be greater than a factor of two; it may be best therefore to assume a retention factor of 0.75 in all sampling as error cannot then exceed 50%, which is well within the experimental tolerance of this class of work. Use of biological sampling methods may help substantiate this, though they too contain a large factor of uncertainty. It is perhaps ironic that these studies are made to correct theoretical performance of respirators when the information should really be needed to estimate exposure of the worker & retention of the hazardous substance.

2.4 Measurement of Respirator Performance

James S. Johnson, Lawrence Livermore National Laboratory.

Presented for discussion stimulated workplace study results which are to be reported at AIHC in May.

Points made include:

- practice of fireman to carry, but not often wear, SCBA.
- selection of respirator does not finish with measurement of ambient concentration and selection of respirator certified as of appropriate performance. Managers of programs must confirm that adequate protection is actually being obtained (ANSI Z.88.2) - how?
- hygienist should advise appropriate selection based on "average" protection factor in standardized conditions
- Need to limit GSD of WPF's. Believes responsibility is that of the practising hygienist not the regulating authority.
- new methods of urine analysis strengthen case for audit by biological monitoring.

2.5 An Objective Method for Setting Assigned Protection Factors

Robin M. Howie, Institute of Occupational Medicine, Edinburgh, Scotland

This paper suggests that rather than aim to assign high protection factors where exposure to highly toxic substances may occur, the reverse criteria should be applied. Where the consequences of failure are great, then risk will be minimized if only a low protection factor has been assumed. This system recognizes the great and unpredictable variability of protection achieved in the workplace.

It is proposed that standards setting bodies should assign Standard Protection Factors to different classes of devices, and that users* should select respirators based on APF's appropriate to their own workplaces taking into account the following relevant factors:

- toxicity of the substance
- its warning properties (<TLV/10, about TLV, >TLV)
- the concentration present (< or > IDLH - a measure of immediate risk in event of failure)
- duration of wear (<30 min, 30-60 min, >60 min - lower acceptability for long periods)
- training
- supervision

Proposed toxicity classification:

Toxicity	Examples
"low"	mild irritants, nuisance particulates, simple asphyxiants, IDLH >100xTLV
"medium"	irritants, narcotics, weak chemical asphyxiants, fibrogenics IDLH <100xTLV
"high"	occupational carcinogens moderate + chemical asphyxiants sensitizers, allergenics acutely toxic substances

Setting the APF in the Workplace:

APF 1: toxicity, concentration & warning properties

	Toxicity - Concentration			
Subjective Detection Level	"low" <IDLH	"medium" <IDLH or "low" >IDLH	"high" <IDLH or "medium" >IDLH	"high" >IDLH
<TLV/10	SPF	SPF/2	SPF/4	SPF/8
about TLC	SPF/2	SPF/4	SPF/8	SPF/16
>TLV	SPF/2	SPF/8	SPF/16	SPF/32

APF 2: duration of wear APF 3: training & supervision

Duration			Training & supervision	
<30 min	30-60 min	>60 min	proven good	unproven
x4	x1	x1/2	x2	x1

Then **APF** = APF 1 x APF 2 x APF 3

* users are taken to be the employers of workers who wear respiratory protection

Examples of required Standard Protection Factors are given for substances present at 50 x TLV.

Substance	Effect	TLV	IDLH	SPF
NaOH	Irritant	2 mg/m^3	125xTLV	200
Xylene	Irritant narcotic <cell count	100 ppm	10xTLV	800
Crocidolite	fibrogenic carcinogenic	0.2 f/ml	Ca	3,200

2.6 & 2.7 Determining Workplace Protection Factors for Negative-pressure Elastomeric and Disposable Half Mask Air-purifying Respirators: Phase 1- Foundry Operations and Phase 1- Aircraft Painting

Warren R. Myers, Department of Industrial Engineering, West Virginia University.

See also 1.1 - 1.3 and 2.22 above.

Information presented on slides is not available but is assumed to be similar to (or identical with) that reported earlier. This presentation largely concerned sampling techniques rather than results - which can be found in earlier references and are still in progress.Some points are:

- using PIXE analysis and determined WPF's on basis of Zn determination.
- measured respirable outside respirator by cyclone, and total aerosol inside.
- SEM showed large particles(>10um) on inside facepiece filters, and PF's as low as 3 & 10 on elastomeric respirators.
  source of contamination is unknown source but glass fiber from filter suspected.
  (see 4.40 on fiber release from filtering facepiece respirators)
- Cl and Si can show higher concentrations inside facepiece than outside.
- difference of WPF's in paint spraying (2,000-6,000) & in foundries (c.100) may be due to odor detection* or difference in workloads. These details are given:

Paint spraying (measuring Ti or Cr)	GM 3988	GSD 4.1
Foundry (measuring Zn)	GM 119	GSD 4.4

Studies used same respirators but different cartridges

- cost of study about $300 per data point (much uncertainty on this)
- confirmed major issues are condensation of vapor in sampling casette and losses due to wall deposition
- A large number of slides showing field observations were shown, but transcribed description is inadequate to reproduce them.

Discussion indicated too many variables in present systems, too many uncertainties in past field measuring programs, and significant variation dependent on particular operations. It is vital to determine whether daily or within day variation precludes standardized tests. It appears that in-facepiece measurements of high performance respirators brings us into "discrete" particle problems - as for radioactive substances (page 12, paragraph 2).
Limits on WPF determination depend on ambient concentration. Apparently no measurements have been made on in-facepiece concentration in clean air zone; check out in a clean room? The audience were invited to decide whether tests on 4 respirators showed significant differences in performance: no one responded.

* Myers reported his own experience of being able to detect MEK whenever a temporary leak occurred (eg on turning his head)

2.8 Workplace Study of Powered Air-purifying Respirators

Donald H. Burd, Racal Health and Safety.

Reported too briefly on a study in a Canadian aluminium plant of benzoapyrene.
Indicated for PAPR's GM = 1500; 5%ile = 250, and somewhat lower for half-masks.
Presented opinions that:

- WPF's are not relevant at this stage - techniques are not reliable or reproducible
- workplaces studies should be continued, but not to develop a certification method
- standard protocols using trained monitors are required
- particular problems include: finding and training participants, covering several shifts, and transferability of data between groups and environments.

He listed the many problems that can occur in field studies and stressed the need for comprehensive planning.

2.9 Performance Criteria Document

John H. King, E.D. Bullard Company.

This is a 72 page document, too extensive to review in this report; included are 5 pages of definitions, 7 pages on APR's, 8 pages on PAPR's, 6 on SAR's, 11 on open-circuit SCBA's and 12 on closed circuit SCBA's. Each section follows a standard format, but some details have yet to be included. The final version is likely to prove an extremely valuable document.
Lively discussion picked out a number of significant points that will probably be considered before final publication.

2.10 Results and Methods from Eleven Workplace Tests

Craig E. Colton, 3M Company.

This paper summarized nine studies made since 1984; they are probably listed as 1.5, 1.6, 1.7, 1.8, 1.9, 1.10, 1.11 and 1.12 above.
AIHA terminology is used throughout: WPF requires simultaneous measurement during use. Workers must be trained. Respirators must have been selected, be in good condition and fit tested.

Notes taken include

- 12 brake pad workers exposed to asbestos: 25% inside samples < sensitivity; 10% outside overloaded. All WPF's of half-face masks showed best estimate of 5%ile >10
- PAPR worn at offing granule plant: 5%ile WPF with shroud 1484;without shroud 54
- air supplied sand blast helmet: (see 1.12) at 10x field blank: WPF - GM 2143; at 1200X - GM 4023.
- samples rejected because outside loading insufficient to indicate the appropriate WPF.
- airline respirator/helmet? in foundry showed following results (from 1.10):

Substance	Load	GMWPF
Fe	>25x field blank	273
Fe	>750x	1012
Si	>25x field blank	360
Si	>750x	1417

- disposable half-face aircraft fabrication; 5%iles WPF - Al 32; Ti 24; Si 24.
  Sensitivity of PIXE 9-35 ng, sees only center of filter. This is critical if millipore casettes used as heavy center deposit likely. 3 piece cassette produces more uniform deposit.
- Full facepiece at secondary lead smelter: WPF 5%ile 95 with GSD of 9.61 up to 299 where mass collected was high. Quantitative fit tests did not predict WPF.
- PAPR as above WPF 5%ile = 728 (35 sample sets are excluded as internal sample <detection limit
- Half mask at aluminium smelter doing heavy work during carbon charging: WPF 5%ile = 13
- High efficiency disposable, moderate/heavy workload in brass foundry; not all users were clean shaven. WPF 5%ile: Pb = 28; Zn = 40. Evidence of loading dependence.

A critical question on these studies is whether the results were averaged over all measurements, and, if so, were they markedly worse for any one worker? More likely with full facepiece respirator?

2.11 Technical Concerns Associated with Workplace Protection Factor Testing

Alan R. Johnston, 3M Company.

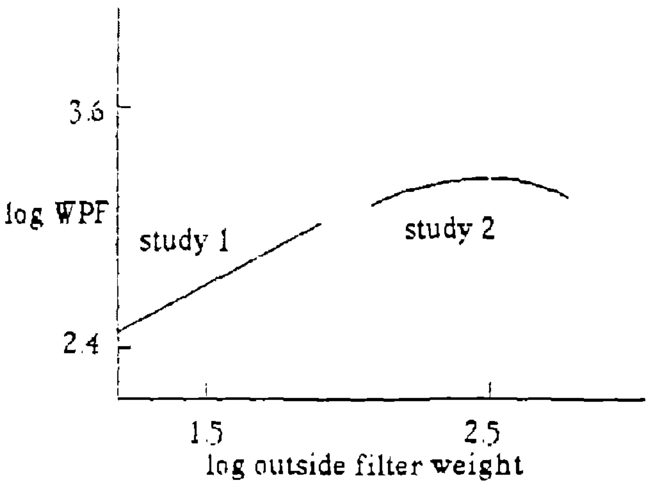
This reviewed all the factors that bear on WPF determination which are too numerous to detail here. It concludes with the comments that accuracy and reproducibility needed are not currently available, it is not possible to standardize test protocols, sample collection, analysis and interpretation. Research will likely address many key issues but the variables may be too numerous for the system to succeed as a certification tool. Many of the practical difficulties that arise in setting up field studies are discussed, and many problems requiring solution are identified. It can be predicted that great difficulty will be found in identifying representative workplaces where managements and workers will accept the interference and additional work that workplace testing incurs; indeed, for many substances there may be insufficient test sites available in the US.

Some points from presentation:

- introduction: promising tool, variables not yet defined, results not yet reproducible. most prior studies are not strictly WPF tests and experience with WPF tests is very limited.
- background: certification must be controllable & reproducible to be relied on, WPF tests must be standardized, extrapolation to other workplaces must be possible,
- standards required for: terminology, test site and subject selection and preparation, procedures for sampling, sample evaluation, statistical analysis

In preparing for WPF tests the number of factors found to be important when selecting each aspect are:

site considerations	20	sampling concerns	4
test subject considerations	7	sampling methods	6
test subject selection	7	analytical methods	4
test subject variables	4	data analysis	4
fit testing	3	suggested data rules	11
research needs	4	sample loading	5



WPF value is dependent on loading of filters, and thus on ambient air concentration and duration

Questions:

1. is performance testing required for certification?
2. which is preferable, workplace testing or simulated workplace testing?
3. how well can test conditions represent actual working conditions?

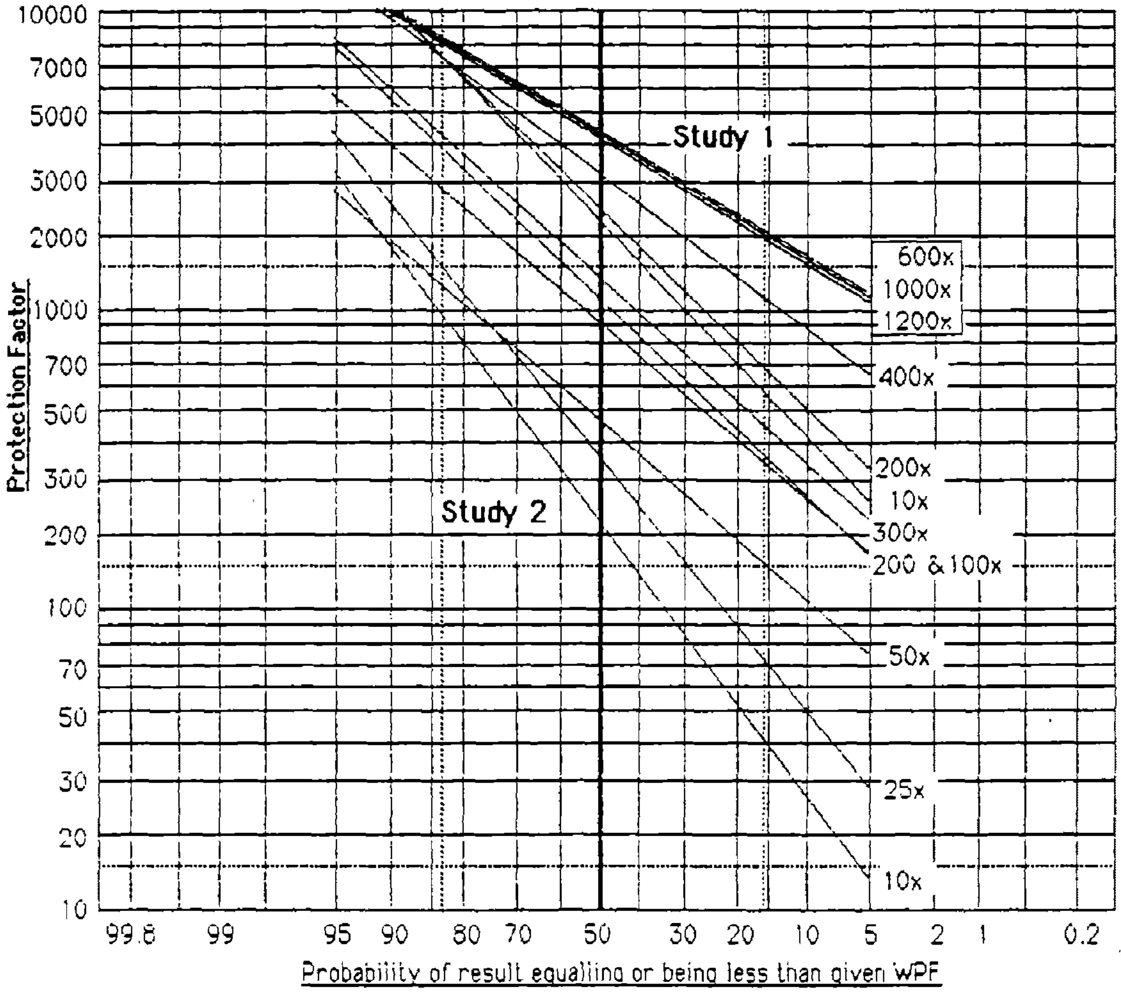
Conclusions:

1. WPF testing can be useful
2. standardized methodology is not yet defined
3. there are significant concerns about reproducibility of test results
4. such testing is not appropriate for certification purposes

An unexplainable feature of a number of field tests is the dependence of WPF on filter loading, as shown:

Effect of Particulate Concentration on WPF

Dependence of WPF on dust loading of outside filter (expressed as multiple of field blank)



2.12 Panel Discussion-Feasibility of Workplace Testing and Alternatives

.1 Individual Assigned Protection Factors, Richard D. Grunberg (MSA)

Analogy is made with automobile testing requirements (deemed successful) and those for hearing protectors (deemed unsuccessful). The 1991 ANSI Z88.2 fit requirements which assume a factor of safety of 10 are considered workable. Improved design of respirators is driven by fit testing which has grown from perhaps 10% of workers in 1980 to about 75% today. A number of factors can influence the protection achieved in the workplace.

.2 Infeasibility of Conducting Workplace Testing. Donald H. Burd (Racal)
Precisely quantifying performance of individual respirators is not technically possible today, though in theory it could provide the best information on protection. It is extremely difficult to find workplaces with sufficiently high concentrations to enable high fit factors to be determined. Other restricting requirements include the presence of a large number of workers in the contaminated area for sufficient time who, with management, are willing to participate in studies. A number of problems inherent in the testing system are considered.

.3 Alternatives for Assigning Performance Levels. Donald P. Wilmes (3M)
Four steps are recommended to enhance confidence in the certification process:

- test respirators in the laboratory using upgraded bench tests
- perform fit tests on a ten person anthropometric panel
- conduct simulated workplace testing with the same panel
- field evaluate all certified respirators

More details are given and reference made to the following presentation.

2.13 Cost Analysis

Ronald E. King (3M)

This was the only paper devoted to this all-important subject and reviews costs based on experience of the company. Six essential steps are identified and costed:

Step	People-days	Cost ($)
Preparation	30	
Pretest visit	3	1575
On-site tests	30	9950
Sample analysis		10,500
Data analysis	20	
Report writing	20	
Total people-days	103	
Labor cost at $90/hour		74,160
Total cost		96,185

Each study is assumed to obtain only 25 acceptable data points; the cost of obtaining 126 data points as suggested by NIOSH would be $484,722. A full-line manufacturer may make 20 submissions for approval and 30 updated submissions,
his overall cost is then estimated to be $24,236,100.
(This enormous sum prompts consideration of overall manufacturing costs and profits).

2.14 Workplace Protection Factor Study of Negative Pressure Full-Facepiece Dust Respirators During Asbestos Removal

Susan N. Tannahill, Strathclyde University, Glasgow, Scotland.

Measured workplace protection factors for asbestos

	N	Range	GM	GSD	5%ile
Respirator A	25	11-3411	264	4.3	26
B	18	26-8717	720	3.99	79
C	6	17- 500	120	4.4	11

Variation of WPF between workers is less than the variation on each worker
No decrease in performance up to 3 days facial hair growth.

2.15 Evaluation of Respirator Fit Testing by Controlled Negative Pressure Technique

Clifton D. Crutchfield, Division of Community & Environmental Health, Univ. of Arizona.
See references 3.2-3.5 in New Material section.

The controlled negative pressure technique was shown to give more consistent measurements of facepiece leakage than aerosol testing, and an order of magnitude lower. This is attributed by the presenter to non-representative aerosol sampling within the facepiece.

A negative pressure of 0.5" of water and a flow of 26 L/min were selected in comparative testing of 125 Air Force personnel. Thirty male and female subjects were tested on an ergonometer when wearing respirators of three different resistances. Negative pressure was dependent on work rate.

Full face masks required harder work due to dead-space effects (US respirators do not have to have an inner cup). Leakage only occurs when pressure in facepiece is negative; this nullifies Rainbow passage test as speaking is done only on exhalation (pressure found to be about +0.1"). A future ANSI requirement will be that a full inhalation must be made when the head is turned sideways to ensure pressure goes negative. He estimates that a proper fit test will take about 45 minutes for each worker.

2.16 Limitations of Current WPF Studies and OSHA's Experience with Simulated WPF Studies

Ching-tsen Bien, OSHA Directorate of Technical Support.

The principle factors to be considered in WPF studies were reviewed, and the LASL studies (see 3.1 below) reported. Recommendations included:

respirators should be worn in tests lasting not less than 5 hours
tests should be made at high temperatures and humidities
WPF studies should be conducted at high work rate to induce stress
analytical tests should be standardized with at least 3 recognized independent laboratories
reports to be confined to test conditions

It was proposed that WPF studies can be evaluated by assigning points to different factors, such as particle size, ambient concentration, work rate, analytical method, etc. It is considered that a study is only representative if 55 or more points are obtained. This approach is unrealistic, as a study should be rejected if any one factor is defective. Tests of emergency escape respirators shows that oxygen concentration may fall rather rapidly in 2-5 minutes use.

A number of WPF tests for lead are reported on Survivair-2000 half-face respirators with high-efficiency particulate filters
Duration is not reported and WPF's range from 52.9 to >36,100.
Two subjects have sufficient test results to be analyzed:

Subject	N	Range	GM	GSD	5%ile
1	18	>35,400-216	4240	4.57	370
2	12	>36,100-126	3200	4.13	320

Test results from two other studies are reported in a table, but the calculations may erroneously sum WPF's rather than penetrations. Nevertheless they are reported here:

Study	N	Range	GM	GSD	5%ile
1	25	2,200-28	180	4.1	18
2	42	36,000-53	3400	3.8	390

2.17 Feasibility of a New Method to Determine Respirator Protection Factors by Breath Analysis

Clifton D. Crutchfield, Division of Community & Environmental Health, Univ. of Arizona.
See references 3.2-3.5 in New Material section.

PF's were determined by measuring Freon 113 in exhaled breath 30 minutes after 30 minute exposure test subjects were calibrated without a respirator. Comparison with negative pressure fit test indicates that the latter underestimates leakage by a factor of about 2.5, though skin absorption of Freon is possible. Bag samples taken from the mask during exposure did not correlate with subsequent breath determination. It is hoped to develop more definitive studies following this pilot trial.

2.18 Validation of a Simulated Workplace Protection Factor Measurement Protocol

Robert A. da Roza, Lawrence Livermore National Laboratory.
See notes on internal report by Da Roza and Sackett, 3.6 following.

Detailed testing of the exposure and measuring equipment is described, with cross-checking of aerosol (PEG aerosol spiked with fluorescein) and vapor (SF_6) systems. Mannequin head on a breathing machine was used with hypodermic needle leakages. The Phoenix photometer was found linear over 5 decades. Using 3/16" ID line 20 ft long, aerosol loss was only 1.4%. Vapor concentration was determined with Leakmeter II by ITI and a Miran 1A.
Positive pressure masks were found to "go negative" at high work rates - with a 3/8"hole in the facepiece a PF of >7,000 at 55 L/min fell to less than 10 at 65 L/min. A large subject using 80% cardiac reserve (105.8 L/min) did not obtain a good fit factor. The system used could not detect any leakage through the exhalation valve. Maximum variation of in-mask sampling results were 1.5 at forehead and cheek leaks, and 2 at temple; mouth sample was always low, and lens sample was least representative. Vapor and aerosol gave similar results. Negative pressure occurred in facepiece at 60 L/min with 4 cfm supply, and at 80 L/min at 6 cfm.

2.19 Concept of Simulated Workplace Testing of Respirators

Barry J. White, The Jefferson Group.

Representing the ISEA he called on NIOSH to adopt the appropriate language of the new ANSI Z88.2. giving justification for so doing. Specifically to adopt the term "assigned protection factor" as it includes the words "expected workplace level of respirator protection that would be provided by a properly functioning respirator or class of respirators to a properly fitted and trained user". He approves of use of factor of ten between facepiece fit test result and actual protection gained in the workplace. He states with respect to objective of "developing a detailed protocol for conducting workplace protection factor tests that would apply to all workplace settings, all contaminants and all respirator types" that "it is not possible at this time to develop such a detailed protocol". However, NIOSH should explore simulated workplace testing and reviewers comment on how it should be performed. Primary problem is poorly managed respirator programs. Consider carefully work being done by both Z88.2 and Z88.9 committees.

2.20 A Simple Test Method for Respirator Cartridge/Canister Effectiveness Against Specific Chemical Challenges and Work Conditions

M.F. Suzanne Pinette, TRI/ENVIRONMENTAL INC.

This paper described a standardized rig to test cartridges and canisters against known concentrations of vapors or gases. It was not concerned with workplace testing.

2.21 Reinstallation and Justification for Using Laboratory Face Fit Testing as the Principal Means for Respirator Selection

Trenton A. Niemeyer, FILCON Corporation.

It is concluded that facepiece testing is not sufficiently developed to be used to assign protection factors and wearers can only be assured adequate protection by individual testing. Only laboratory testing is acceptable and a factor of safety of 25 should be allowed initially. It may be necessary to modify this later.

For PAPR's the assigned protection factor of 25 appears reasonable, but no conclusions can be drawn from laboratory tests on filtering respirators as no correlation with workplace factors has been observed. Detailed literature review is made of likely causes for this, and the wide range of possible inhalation rates is considered significant.

A new and more detailed anthropometric model of the face is developed, recognizing 12 potential leakage sites for half-masks and 16 for full facepieces; measurement of the third dimension cannot be done adequately. Effects of dead space are considered and finally attention given to the significance of the 5%ile. If 1 million workers use respirators, 50,000 could be adversely affected.

2.22 The Process of Assigning Protection Factors Used by the ANSI Z88.2 Committee

Thomas J. Nelson, Du Pont Company,

This presentation was not available, but data used by ANSI Z.88.2 Committee was provided. APF's are based on grouped data and cannot be assigned to individual respirators. A hierarchy of test results is used: workplace studies, simulated workplace studies, fit test studies, any other data.
Greatest research need is to determine sampling bias of facepiece probes.

Key test data is tabulated below:

Powered Air Purifying Respirators							
Study	Substance	Type	Unit	Conditions	Geo Mean	Std.Dev.*	5%ile
NIOSH-1	Silica	WPF	HF MSA	Mod/Heavy	380	2.6	79
NIOSH-2	Silica	WPF	,,	,,	54		18
Myers-1	Lead	WPF	3MW316	,,	165	3.6	20
Myers-2	Lead	WPF	AH3 Racal	,,	205	2.8	38
Myers-3	Lead	WPF	3MW316	,,	135	1.9	50
Myers-4	Lead	WPF	AH5 Racal	,,	120	2.6	25
Ayer	Silica	Lab	FF MSA	Heavy	3400	2.8	500
Los Alamos	Lab Simul		HF MSA Racal 3M	Heavy	>10,000 >2,500 >4,000		
Du Pont	Dust	WPF	3MW316	Mod/Heavy	230		25

* Geometric standard deviation assumed

Half Facepiece Respirators							
Study	Substance	Type	Unit	Conditions	Geo Mean	Std.Dev.	5%ile
NIOSH -Campbell		PF		Mod/heavy	180		18
Du Pont	Lead	PF		,,	2400		160
Du Pont	Blood/lead	Exposure	,,	26			
Du Pont	Asbestos	WPF	5 types	Mod/wet	94-600		10-55
CMA	Cadmium	WPF	3M9900 Survivair	Moderate	320		20

Forthcoming recommendations based on 5%iles are:

Type	APF
Fit tested half masks	10
Fit tested full face masks	100
Air supplied, half mask	10
,, ,, full face mask	100
PAPRs, loose fitting	25
,, half mask	50
,, full face with HEPA filter	1000
,, hood or helmet	??
Positive pressure SCBA	no value given

Section 3 Material Received After the meeting

3.1 Effects of Temperature and Humidity on Respirator Fit Under Simulated Work Conditions

B.J. Skaggs, J.M. Loibl, K.D. Carter & E.C. Hyatt, Los Alamos Rep. NUREG/CR-5090 LA-11236.

Describes program of testing 7 respirators of different types on 8 men, 2 women. Initial standard facepiece fit test using di-2-ethylhexyl sebacate (DEHS) to Los Alamos standards, followed immediately by work simulation tests in environmental chamber at 6 different conditions of temperature and humidity.

Initial problems: 3 MSA PAPR Comfo half-face - 1 battery required replacement
3 3M PAPR (W344) - plastic hinges on visor broke
3 Racal AH3 PAPR - 2 leaked where wires enter battery compartment
only one unit repairable.

Prefit test FFs

Device	Make & model	Selection Criterion	%* subjects achieving criterion in all tests
PAPRs	Racal helmet	1000	60
	3M helmet	1000	90
	MSA with Comfo	1000	100 (90 >10,000)
Supplied air	Survivair	10,000	90 (1 only 400, stuck exhalation valve)
Continuous flow hood	Bullard	10,000	100 (2/2)
Filter type	MSA Comfo II	1000	40
	MSA UltraTwin	3000	20

* each based on 10 subjects, other than Bullard hood.

Analysis of prefit FF's for filter respirators (based on 6 tests per subject)

Subject	Comfo II				UltraTwin			
	Arith. Mean	Actual Mean	Median	GSD	Arith. Mean	Actual Mean	Median	GSD
1	9,500	4,400	6,500	2.8	15,400	13,000	14,300	1.6
2	14,800	8,000	11,700	2.4	8,700	4,100	6,400	2.6
3	7,300	350	1,700	9.5	11,000	6,100	7,700	2.7
4	5,400	100	510	17	2,900	770	1,100	6.0
5	2,900	510	850	4.6	3,400	900	1,600	4.3
6	3,400	40	150	14	8,700	4,700	6,300	2.5
7	17,400	15,300	16,500	1.5	8,900	5,600	7,100	2.2
8	5,900	120	810	17	11,600	1,100	5,400	6.1
9	17,600	14,300	16,200	19	16,500	1,600	16,000	1.3
10	7,000	100	750	7.0	5,600	450	1,800	7.0
Mean	9,100	4,300	5,600	9.5	9,300	3,800	6,800	3.6
Av FF GSD		760 9.9				2,330 3.0		

Note: GSD are of samples. Population GSD's are significantly lower where GSD is high (eg s = 19, sigma =14). Statistics on 6 samples are not reliable.

Overall test results: number of subjects failing to meet criterion (No. tested = 10)

		Criterion	Environmental chamber conditions					
Temperature (°C)			0	0	21	21	32	32
Humidity (%RH)			15	85	15	85	15	85
Device	Test							
Racal helmet	Prefit	<1000	1	0	2	0	2	1
	Prework		0	0	2	1	5	4
	SimWork		4	1	2	3	3	5
	Postwork		3	2	4	4	4	8
3M helmet	Prefit	<1000	0	0	0	0	0	0
	Prework		0	0	0	0	0	0
	SimWork		1	2	0	0	2	2
	Postwork		0	0	0	0	1	1
MSA PAPR with Comfo	Prefit	<1000	0	0	0	0	0	0
		<10,000	0	1	0	0	0	0
		<20,000	0	1	2	0	2	1
	SimWork	<1000	0	0	0	0	0	0
		<10,000	2	2	0	0	0	0
		<20,000	5	3	0	3	0	2
Survivair supplied air	Prefit	<1000	0	0	0	0	1	0
		<10,000	0	0	0	1	1	0
		<20,000	0	0	1	2	2	1
	SimWork	<1000	0	0	0	0	1	2
		<10,000	0	0	1	0	1	3
		<20,000	1	1	2	0	2	5
Bullard	SimWork	<20,000	0 on only 2 subjects tested (facepiece dislodged in one test, >2% leak)					
MSA Comfo II	Prefit	<50	0	0	0	0	0	0
		<100	3	0	2	1	2	3
		<1000	4	2	4	3	3	5
	SimWork	<50	0	0	0	0	0	0
		<100	1	1	2	3	3	3
		<1000	5	2	3	4	3	6
MSA UltraTwin	Prefit	<50	0	0	0	0	0	0
		<100	0	0	0	0	0	0
		<1000	2	0	0	2	2	1
	SimWork	<50	0	1	0	0	1	1
		<100	1	1	0	0	1	1
		<1000	2	5	1	3	2	3

Fit Factors for Comfo II during Workplace Simulation

Temperature (°C)	Arithtic.	0		21		32		Average
Humidity (%RH)	mean	15	85	15	85	15	85	FF
Subject No			Fit Factor					
1	15,300	15,000	18,000	18,000	16,000	5,600	19,000	13,000
2	12,600	13,000	3,600	14,000	16,000	20,000	9,100	9,300
3	7,400	20,000	20,000	100	3,700	90	560	260
4	9,200	90	20,000	50	18,000	17,000	50	120
5	2,900	300	60	50	50	17,000	100	90
6	2,600	100	40	6,100	2,800	6,300	70	120
7	6,900	11,000	10,000	20,000	300	40	100	160
8	7,300	300	20,000	20,000	40	3,500	60	130
9	18,300	15,000	20,000	19,000	18,000	20,000	18,000	18,000
10	8,900	200	17,000	16,000	60	20	20,000	80
Means	9,100	7,500	12,900	11,300	7,500	9,000	6,700	4,130
Average FF GSD of averages		1,590 10.6	4,600 11.6	2,930 14.6	1,410 13.9	2,000 15.8	770 14.7	510 9.6

The above results do not follow log-normal distributions; results cluster at <300 and >10,000

A note on significance:
Assume that subject 4 achieves the above values on 6 successive days;
calculate the mean exposure during the week?

True Mean $= \frac{1}{90} + \frac{1}{20{,}000} + \frac{1}{50} + \frac{1}{18{,}000} + \frac{1}{17{,}000} + \frac{1}{50} \div 6$

$= 0.01 + 0.00005 + 0.02 + 0.00006 + 0.00006 + 0.02 \div 6$

$= 0.0085$

Mean FF for week = 120 not 9200

A series of FF tests cannot be averaged to determine an average index of protection
The reciprocals (penetrations) must be summed, divided by N, and converted back to FF.
(See further example calculation in Appendix 2).

3.2 Evidence of Significant Aerosol Loss and Consequent Overestimation of Fit During Quantitative Respirator Fit Testing. (Draft)

Clifton D. Crutchfield, Richard W. Murphy and Mark D. Van Ert.

This describes a series of tests in parallel to compare measurement of facepiece fit by in-mask probe sampling and negative pressure measurement. On 125 test subjects the correlation (rounded to values) was found to be: negative pressure fit factor = 0.5 aerosol fit factor + 0.9 (r=0.72)
A series of 32 tests on a single subject, showed good correlation (r=0.989), but aerosol fit factors were 2 to 16 times those indicated by negative pressure measurement.

3.3 Feasibility of a New Method to Determine Respirator Protection Factors by Breath Analysis.

John A. Decker and Clifton D. Crutchfield (Draft).

This describes a non-workplace method of determining percentage penetration by measuring the concentration of chlorofluorocarbon 113 in exhaled air 25,30 & 35 minutes after completing test exposure lasting 30 minutes. Comparison of first results with other testing methods is summarized as:

1. good correlation (r = 0.86) with negative pressure tests, though leakage indicated by the biological method was about 2.5 times that determined by negative pressure.
2. poor correlation with probe sampling in mask (r=0.24).

3. no correlation (r=0.003) between probe sampling and negative pressure tests. This differs from that reported in the 3.2 above where reasonable correlation (r = 0.723) was found.

This technique raises more questions than it answers and further studies are required to resolve the numerous uncertainties.

3.4 A Comparison of Negative Pressure and Aerosol Quantitative Respirator Fit Test Systems Using Fixed Leaks

Clifton D. Crutchfield, Richard W. Murphy and Mark D. Van Ert.

Results from the two methods were highly correlated (0.998) with aerosol fit factors averaging 37% higher. This is attributed to aerosol losses in the hypodermic needles used as fixed leaks.Detailed statistical analysis revealed nothing remarkable. These results differ markedly from those reported in 3.3 and 3.5, and call for further evaluation of all techniques

3.5 Determination of Inspiratory Pressures and Flow Rates for Work Dependent Quantitative Respirator Fit Testing

Clifton D. Crutchfield, Trinh K. Pham and Mark D. Van Ert.

It is probably self-evident that leakage into facepieces only occur when internal pressure is below ambient. This reports investigation of conditions when this occurs to determine challenge pressures and flow rates for negative pressure tests. Half-mask (MSA Comfo) and full-face (MSA Ultraview) respirators with low, medium and high resistance filters were tested on male and female subjects at four work rates.

Inspiratory pressure was dependent on work rate and cartridge resistance, and was 15% higher for males. It was 22.5% higher for the full facepiece respirator, probably due to greater dead space. The range of mean inspiratory pressures was 0.2 - 0.5"H_2O for low resistance cartridges, and 0.6 - 1.7"H_2O for high-resistance for work rates in the range 90 - 540 Kg/min.

Inspiratory flow rate was strongly correlated with work rate but not with filter resistance; there were no differences between males and females. Both inspiratory pressure and flow rate was lower for the half-mask than the full-facepiece respirator, probably due to the latter's greater deadspace.

3.6 Validation of Experimental Strategy for Respirator Testing

Robert A. da Roza and Carol Sackett, report for E.I. du Pont de Nemours, 1988.

This describes a major and thorough evaluation of test techniques with PEG 400 aerosol spiked with fluorescein and with sulfur hexafluoride vapor; there was good correlation between the two methods. The tests were made on a MSA UltraVue mask fitted to a mannequin head and breathing machine and known leaks created at three positions: forehead, temple and cheek. Samples were taken at the breathing machine, mouth, lens and by exhalation tube. Those taken at the lens position showed 20-65% positive bias with respect to those taken by the breathing machine; exhalation tube samples showed very little. In pressure demand mode, exhalation tube samples showed 30% positive bias whereas lens samples averaged 69%. At breathing rates lower than 100 L/min no leaks were detected (pressure inside mask remained positive relative to ambient. Negative pressure at 80, 90 & 100 Lpm was calculated to last 0.15,4.0 & 6.5% of the breathing cycle duration. For constant flow mode all samples were highly biased - presumably due to dilution. Detailed results are given.

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APPENDIX 2

ON THE USE OF "PROTECTION FACTOR" TO ASSESS OCCUPATIONAL EXPOSURE

The effectiveness of a respirator in use can be expressed in terms of Protection Factor or Penetration; the latter is the inverse (reciprocal) of the former. The Protection Factor is the ratio between the concentration outside a respirator and that inhaled by the wearer; Penetration is a measure of the fraction of the ambient air concentration that is inhaled by the wearer. It is often expressed in terms of percent (%).

The usual major cause of reduced protection when a respirator is worn is leakage between the face of the wearer and the facepiece of the respirator. When considering this cause alone the term Fit Factor is usually applied.

Whilst fit-factor gives an immediate indication of effectiveness, and is a relevant index of protection achieved during a single exposure, it cannot be used directly to assess the average (arithmetic mean) of a series of exposures when a respirator is being worn. To determine average of a series of exposures, penetration must be calculated for each period of use, the values summed (time weighted if appropriate) and the average determined. Finally, the inverse of the average penetration is the measure of average protection achieved.

This is most significant when high-efficiency respirators are worn, and variability of fit from day to day is wide.

Assume, for example, that on 4 days of a working week a fit factor of 10,000 is achieved and on the other day only 200. What is the average protection over the whole week?

The arithmetic average is $\frac{10{,}000 \times 4 + 200 \times 1}{5} = 8040$ .. .. (1)

but this is not the protection actually achieved.

The actual protection is largely governed by the low fit-factor on one day:

$$\frac{5}{\frac{4}{10{,}000} + \frac{1}{200}} = \frac{5}{0.0054} = 925 \quad .. \quad .. \quad .. \quad (2)$$

From this it can be seen that, in this extreme, but not impossible, case the average fit factor would underestimate exposure by a factor of 8.7 .. .. (1) ÷ (2)

APPLICATION TO FIELD OBSERVATIONS

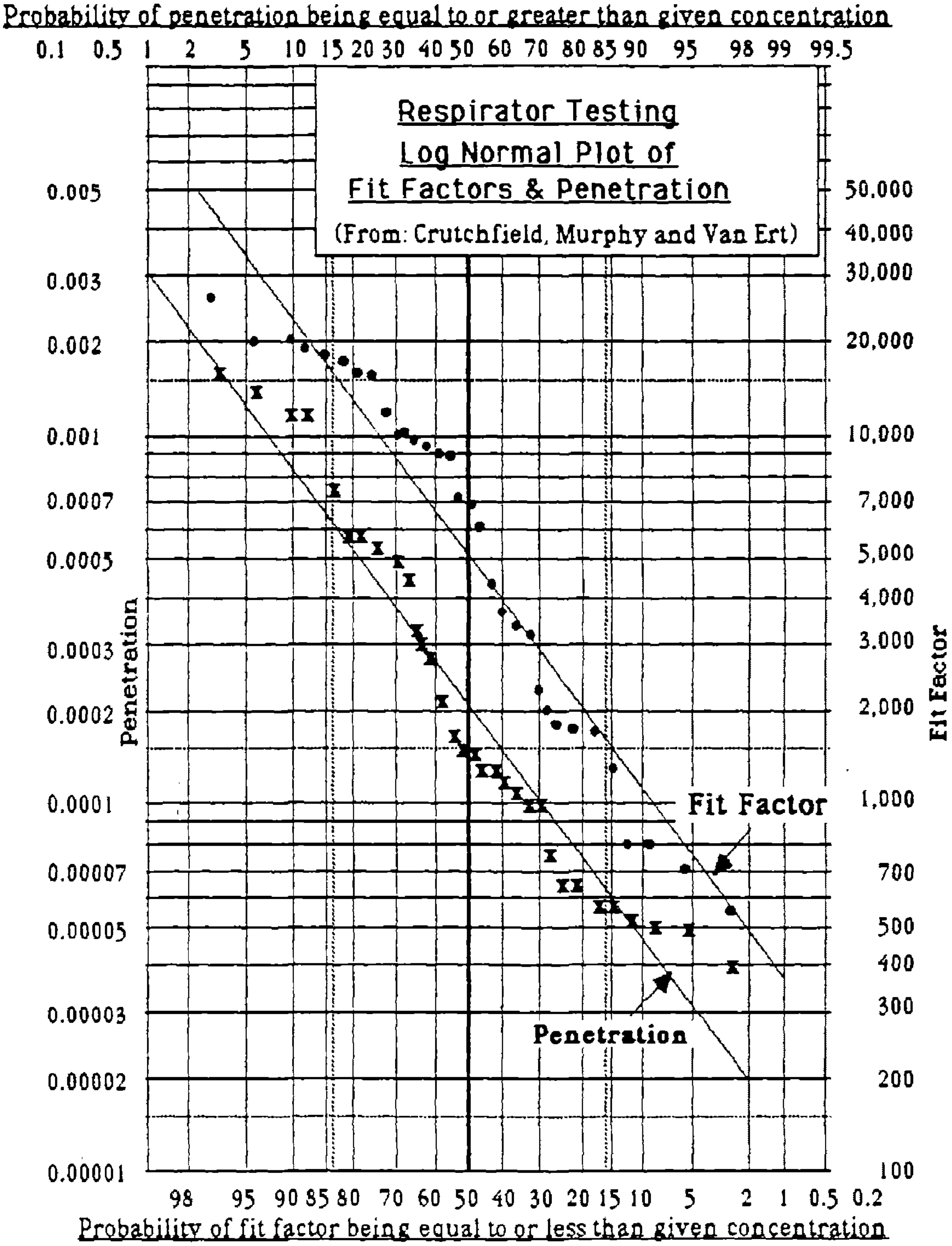
In a draft paper prepared for the meeting(3.2) Figure 4 provides plots of fit factors determined for 1 subject over a period of 32 days. These are measurements made to compare two test systems and do not indicate actual exposures, but are used here to illustrate interpretation of protection that might be achieved over a number of occasions of respirator use. The values have been scaled off a diagram and are not necessarily the precise fit factors measured.

DAILY AEROSOL FIT FACTORS FOR A SINGLE SUBJECT
CALCULATION OF AVERAGE PROTECTION ACHIEVED

Fit Factor	Penetration	Log 10 Fit Factor	Log 10 Penetration
25000	0.000040	4.397940	-4.397940
20000	0.000050	4.301030	-4.301030
13000	7.69E-05	4.113943	-4.113943
16000	6.25E-05	4.204120	-4.204120
16000	6.25E-05	4.204120	-4.204120
19000	5.26E-05	4.278754	-4.278754
20000	0.000050	4.301030	-4.301030
17000	5.88E-05	4.230449	-4.230449
650	0.001538	2.812913	-2.812913
700	0.001429	2.845098	-2.845098
800	0.001250	2.903090	-2.903090
1800	0.000556	3.255273	-3.255273
1700	0.000588	3.230449	-3.230449
1300	0.000769	3.113943	-3.113943
4500	0.000222	3.653213	-3.653213
6100	0.000164	3.785330	-3.785330
3500	0.000286	3.544068	-3.544068
3100	0.000323	3.491362	-3.491362
3300	0.000303	3.518514	-3.518514
800	0.001250	2.903090	-2.903090
1700	0.000588	3.230449	-3.230449
2000	0.000500	3.301030	-3.301030
2200	0.000455	3.342423	-3.342423
9000	0.000111	3.954243	-3.954243
9100	0.000110	3.959041	-3.959041
7000	0.000143	3.845098	-3.845098
7200	0.000139	3.857332	-3.857332
17000	5.88E-05	4.230449	-4.230449
10000	0.000100	4.000000	-4.000000
9000	0.000111	3.954243	-3.954243
10000	0.000100	4.000000	-4.000000
9500	0.000105	3.977724	-3.977724
2750	0.000364	3.710617	-3.710627
AM fit factor = 8370	AM fit factor based on penetration = 2750	GM fit factor = 5140 GSD = 3.09	GM fit factor based on penetration = 1947 GSD = 3.09

5% iles for fit factor and for fit factor based on penetration = about 700.

Values of fit factor and penetration are plotted below on log-normal paper, together with the calculated results. From these the 5%iles for fit factor and penetration are deduced.



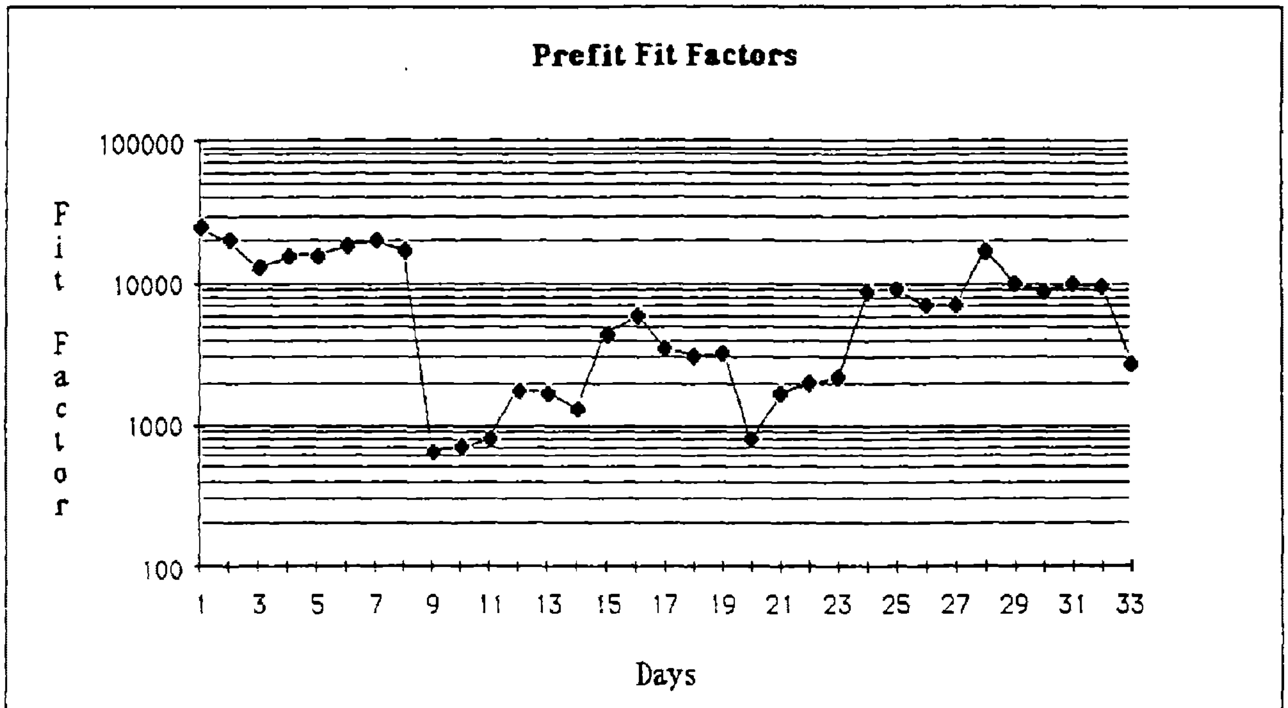
Discussion

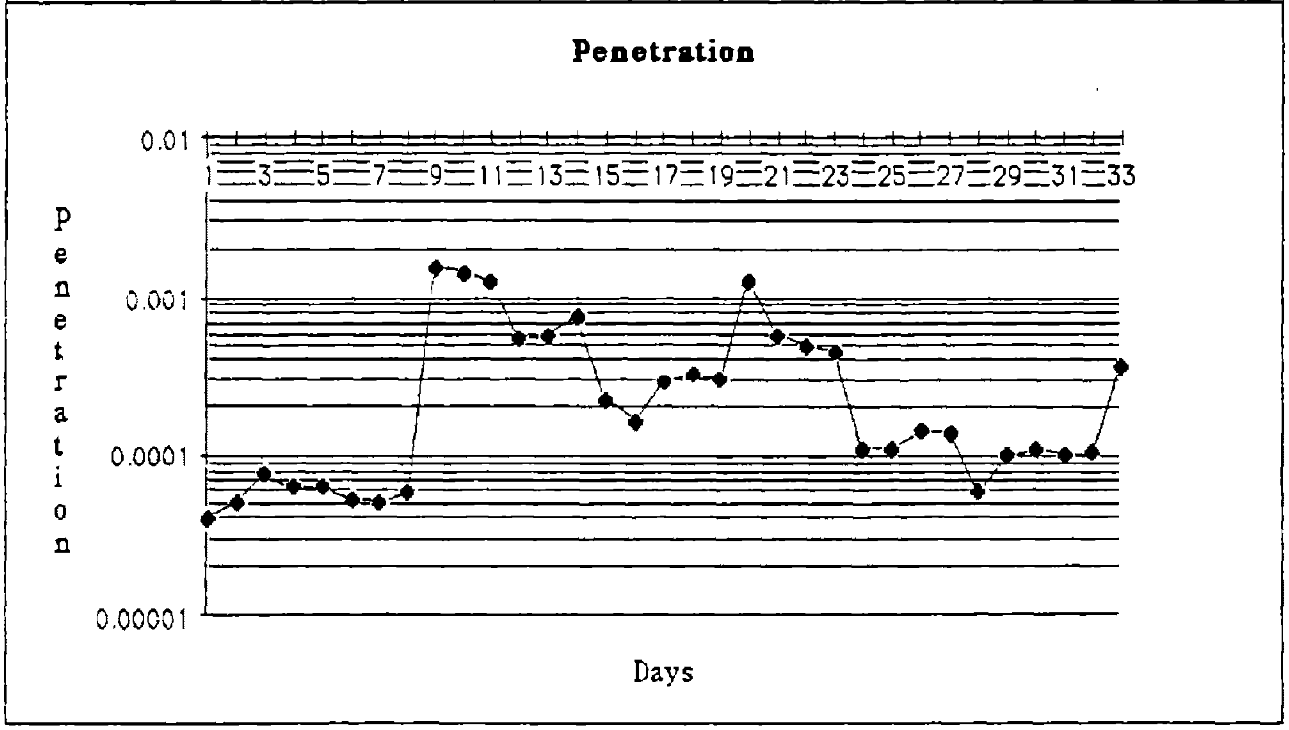
The above plot shows that results of measurements of respirator fit made over a series of test are well described by a log normal distribution. This implies two important characteristics:

1. there is no absolute limit to the minimum fit factor obtainable with a respirator
2. a single measurement of fit factor will most probably underestimate the average factor achievable over a series of usages. This derives from the characteristic of a log-normal distribution that the mode (most likely value) is less than the arithmetic or geometric means.

FIT FACTORS AND PENETRATIONS

Fit tests on both MSA Comfo and Ultra-vue filter respirators were undertaken over a period of one month to compare quantitative aerosol and negative pressure tests. The results of the former are shown below, expressed as fit factors and penetration.





These plots demonstrate clearly that one parameter is the inverse of the other. While the geometric standard deviations (GSD's) of the two are identical, it must be stressed that the average protection achieved over a series of exposures can only be determined by calculating the average of the penetrations. The average fit factor (protection factor) is the inverse of this value.

APPENDIX 3

ON THE APPARENT GAIN OF WPF WITH INCREASE OF SAMPLE FILTER LOADING.

In reference 1.10, Johnston et al show an unexplained increase in the geometric mean of protection factors as the loading of the inside mask sample filter increases. A further anomaly reported is that elemental determine for iron and for silica show different PF's for the two materials. The results are shown below, together with calculated values of arithmetic mean.:

Element:		Fe				Si					
X Field Blank	N	GM	GSD	5%	AM	X Fld. Blk	N	GM	GSD	5%	AM
› 25	39	273	5.7	39	1240	› 10	32	220	5.3	14	880
›100	30	518	4.2	50	1450	› 25	24	360	4.6	29	1150
›200	24	612	3.9	64	1710	› 50	18	482	3.1	75	910
›300	15	770	3.0	125	1408	›100	14	904	2.6	186	1430
›500	12	837	3.4	110	1770	›200	10	1142	3.0	187	2090
›750	8	1012	2.6	199	1597	›300	8	1417	3.0	224	2590

This, and another set of results (see below) showing similar effects are discussed by Johnston in reference 2.11.

Element	X Field Blank	N	GM	GSD	5%	AM
?	10X	37	2143	3.6	259	4870
	200X	32	2340	3.5	324	5130
	400X	28	3135	2.5	673	4770
	600X	22	4150	2.2	1167	5660
	1000x	17	4076	2.3	1038	5770
	1200X	15	4023	2.2	1096	5489

The results are most probably artifacts created by the statistical system applied.
In the first place, the results quoted are dependent on each series of measurements following a log-normal distribution. While this is commonly encountered in field observations, a number of results show a rather different distribution. Particularly when high efficiency respirators are worn, measurements of PF may fall into two classes, very high PF's when the equipment is properly fitted; very low ones when it is not. The table on page 43 shows this characteristic; PF results being clustered at over 10,000, or under 1000. Mathematically, it is very perilous to treat this as a log normal distribution without checking its form.

In the tables shown above it will be noted that the apparent GSD diminishes with increasing multiples of the field blank. If it were appropriate to calculate average protection factor for each set of results, then the arithmetic mean is to be preferred to the geometric mean (which approximates to the median). Calculations based on log-normal assumptions [AM = GM x exp $(s^2/2)$] show that the arithmetic mean is far less dependent on mass of substance collected (see tables above). Unfortunately, average PF can only be determined from the average penetration calculated from the observed values (and not directly from the PF's). In the absence of original data,interpretation must remain speculative; the thoroughness of the field work calls for a fresh assessment of the results using acceptable means of interpretation.

A further order of uncertainty is present as it is not known whether average geometric means have been calculated incorrectly directly from the observations, or whether they have been correctly calculated correctly as the inverse of the sum of values for penetration.

APPENDIX 4

PROTECTION FACTORS - SUMMARY OF DATA

The following tables have been constructed from the data presented in the reference material provided. They represent a wide variety of field studies and involve the averaging of disparate values. They should therefore not be regarded as definitive or precise; but they do show the very wide range of protection factors measured in the workplace for similar equipment is used.

In particular it must be emphasized that the summing of protection factors induces major errors when a wide range of values are averaged, and it should be recognized that statistical analysis of data has assumed log-normal distribution of results. This introduces major uncertainties as protection factors for the more efficient equipment measured in the workplace generally show two ranges, commonly about 10,000 and about 100, with few mid-range measurements. The conclusion must be that research into the cause of major but infrequent leaks should be given the highest priority.

Full Facepiece Respirators

Measured Workplace Protection Factor					
Substance/Process	Substance	GM	GSD	5%ile	Ref.
Lead smelter	Pb	3929	9.6	95	1.8
Asbestos stripping		264	4.3	26	2.14
,, ,,		720	4.0	79	,,
,, ,,		120	4.4	11	,,

Elastomeric Half Facepiece Respirators

Measured Workplace Protection Factor					
Substance/Process	Substance	GM	GSD	5%ile	Ref.
Silica bagging		60	2.5	14	1.1
Lead smelter		180	4.1	18	1.4
Brass foundry	Pb	310	4.3	28	1.9
,, ,,	Zn	681	5.6	40	,,
--	Pb	2,400	5.1	150	1.13
Asbestos		240	6.3	12	1.16
,,		94	3	16	1.16
,,		250	6.9	11	,,
Lead battery	Pb	204	3.6	25	1.20
Styrene		79	3.5	10	1.22
Copper smelting	SO_2	15.3	2.3	4.0	1.24
,,	,,	13.7	2.1	4.3	,,
,,	,,	9.6	2.2	2.5	,,
Painting	Ti	3,988	4.1	430	2.6
Foundry	Zn	119	4.4	10	,,
--	Pb	4,240	4.6	370	2.16
--	Pb	3,200	4.1	320	,,
--	Pb	180	4.1	18	,,
--	Pb	3,400	3.8	390	,,
Work Simulation Study		510	9.6	11	3.1
Quantitative Fit Test		1,000	2	300	1.13
		750	2	220	,,
		5,600	9.5	130	,,
		6,800	3.6	720	3.1
		760	9.9	20	3.1
		2,330	3.0	350	3.1

Disposable Half Facepiece Respirators

Measured Workplace Protection Factor					
Substance/Process	Substance	GM	GSD	5%ile	Ref.
Grinding/polishing	Al	145	2.3	32	1.5
"	Ti	59	1.7	24	"
"	Si	172	3.1	24	"
Aluminium smelter		27	1.5	13	1.7
--		18	3.1	2.5	1.14
Asbestos		310	5.3	20	1.16
"		580	4.2	55	"
"		52	4.2	5	"
(prototype mask)	Hg	41	2.9	7	1.21

Powered Air-purifying Respirators

Measured Workplace Protection Factor						
Substance/Process	Substance	GM	GSD	5%ile	Ref.	Comments
Lead smelter	Pb	205	2.8	39	1.2	
" "	"	165	3.6	20	"	
Lead battery	"	120	2.6	22	1.3	
" "	"	135	1.9	45	"	
Lead smelter	"	380	2	79	1.4	
" "	"	4226	2.9	728	1.6	
Pharmaceuticals	--	11,137	3.9	1197	1.18	
"	--	9,574	3.1	1470	"	
"	--	42,260	9.8	997	"	
Uranium mine	Rn*	18	1.8	7	1.19	new filters
" "	"	5.3	1.8	2	"	after 4 days
Roofing mineral	Si	11700	3.1	1550	1.11	helmet with shroud
" "	"	900	5.2	53	"	" without shroud
" "	"	550	3.0	820	"	" with HEPA
Quantitative Fit Test		7900	2.5	1500	1.2	
		5100	2.4	1100	"	

Self-contained Breathing Apparatus

Measured Workplace Protection Factor					
Process	Substance	GM	GSD	Ref.	Comments
Firefighting	CO	30	--	2.1	
"	Methane	12	--	"	
"	Acetaldehyde	c. 230	--	"	
"	Formaldehyde	c. 60	--	"	

Supplied-air Apparatus

Measured Workplace Protection Factor						
Substance/Process	Substance	GM	GSD	5%ile	Ref.	Comments
Sand Blast	Si	3600	1.9	1150	1.12	Helmet (Min flow)
" "	"	4800	2.4	920	"	(Max flow)
Foundry	Si	21	3.3	3	1.17	
Lead	Pb	12	2.7	2.5	"	
Mine	--	12	2.6	2.7	"	