APPENDIX IV

GRAB SAMPLING STRATEGY REQUIREMENTS FOR DETERMINATION OF RADON PROGENY EXPOSURES

A. Introduction

Airborne concentrations of radon progeny must be monitored regularly to provide the basis for their control. Miners' exposures must be limited to no more than 1.0 WLM per year and the average concentration of radon progeny in any work area must not exceed 1/12 WL during any work shift. The sampling strategy described here was developed after an evaluation of mine sampling data and the typical variability of radon progeny concentrations in underground mines. This strategy will allow the collection of timely and reliable environmental data that can be used as the basis for control of cumulative exposures. This sampling strategy allows for the determination of the arithmetic average of time-varying concentrations of radon progeny during a work shift in a given work area. The determination is based on an unbiased estimate made from grab samples taken at random intervals throughout the work shift. Random sampling of work shifts during a reference period is also included for determination of a long-term arithmetic average work shift concentration. The formulae needed to calculate the statistical quantities used in this sampling strategy are contained in section G of this appendix. The rationale for the critical decision points used in the sampling strategy are contained in section H.

B. Definition of Terms and Notations

STATION: A sampling location within a work area that represents the radon progeny concentration to which miners are exposed.

CLUSTER: Two or more stations at which sampling will be conducted during any work shift. The stations in a cluster should be located at different work areas but must be in close proximity to each other so that alternating grab samples could be taken during the same work shift.

BLOCK OF TIME: A period in which two different sampling days are randomly selected.

AVERAGE WORK SHIFT CONCENTRATION: The average concentration of radon progeny in working levels (WL) during a work shift at a given station.

AVERAGE: The arithmetic mean. The same term can be used for the average of several sample results or for the arithmetic mean of a distribution of concentrations that vary during a continuous period of time. In the latter case, the terms "average," "arithmetic average," and "time-weighted average" are synonymous.

α_i: Average work shift concentration for day i, where i = 1,2,...,12 and day i is the ith day in a time-ordered sequence of the 12 days that were randomly selected from the reference period.

$\hat{\alpha}_i$: Estimate of α_i (based on seven grab samples), where i = 1,2,...,12 and day i is the ith day in a time-ordered sequence of the 12 days that were randomly selected from the reference period.

$\hat{\alpha}_{i+1}$: Estimated average work shift concentration for day i+1 (based on seven grab samples), where i = 1,2,...,11 and day i+1 is the next sampling day following day i in a time-ordered sequence of the 12 days that were randomly selected from the reference period.

$\hat{\alpha}_A$: Estimated average work shift concentration for day A (based on seven grab samples), where "day A" is a term used to designate one of the 12 randomly selected days sampled during the reference period for which the α_i value is in a critical range.

$\hat{\alpha}_B$: Estimated average work shift concentration for day B (based on seven grab samples), where day B is the first workday following day A. [Note: Day B may or may not be the next calendar day after day A since a weekend, holiday, or other non-workday may occur between days A and B.]

$\alpha_\bullet$: Long-term average work shift concentration during a reference period from which 12 sampling days were randomly selected.

$\hat{\alpha}_\bullet$: Estimated long-term average work shift concentration (based on seven grab samples per sampling day) during the reference period from which 12 sampling days were randomly selected.

$\hat{\alpha}_{11}$: Estimated average work shift concentration (based on seven grab samples) on the 11th of the 12 randomly selected days sampled during the reference period.

$\hat{\alpha}_{12}$: Estimated average work shift concentration (based on seven grab samples) on the last of the 12 randomly selected days sampled during the reference period.

LCL: 95% one-sided lower confidence limit for $\alpha_\bullet$

UCL: 95% one-sided upper confidence limit for $\alpha_\bullet$

C. Requirements for Routine Exposure Monitoring

1. Two different sampling days are randomly selected from each 2-week block of time.

2. The stations within a cluster are to be sampled on the same workdays and work shifts. All stations within a cluster are to be alternately sampled, seven times on each sampling day, each time in independent random order. During the work shift, the seven periods for sampling of the entire cluster shall be equally spaced in time. For example, the three stations A, B, and C could be considered a cluster and sampled as ABC, BCA, ACB, CBA, CAB, BAC, and ACB during seven successive intervals of approximately equal durations. If it is not feasible to sample in this manner, then sampling can be conducted along the most efficient path but with a different, randomly determined starting point on each day (e.g., BCA, BCA,..., BCA during one sampling day and ABC, ABC,..., ABC or CAB, CAB,..., CAB during other sampling days).

3. The estimated average work shift concentration ($\hat{\alpha}_i$) for each sampling day (i = 1,2,...12) is computed from an analysis of the seven grab samples taken on that day. Formulae for this computation are contained in section G.

4. Whenever $\hat{\alpha}_i$ for a particular station exceeds 0.14 WL, then that station shall be resampled the next workday. [Note: In this case, $\hat{\alpha}_i = \hat{\alpha}_A$, and sampling on the "next workday" (day B) is in addition to the two randomly selected sampling days required in a 2-week block of time.]

a. If $\hat{\alpha}_B$ (the estimated average work shift concentration on the next workday) is $\leq$ 0.14 WL, then exposure monitoring shall continue as described starting at section C,1.

b. If $\hat{\alpha}_B$ also exceeds 0.14 WL, then: (1) steps shall be taken to reduce the radon progeny concentration in that work area by implementing work practices and engineering controls, (2) respiratory protection shall be required for all miners entering that work area, and (3) grab sampling as described in section C,2 shall be conducted on a consecutive daily basis.

Grab sampling shall continue on a consecutive daily basis until the estimated average work shift concentrations on any two consecutive workdays ($\hat{\alpha}_A$ and $\hat{\alpha}_B$) are both $\leq$ 0.10 WL. When $\hat{\alpha}_A$ and $\hat{\alpha}_B$ are both $\leq$ 0.10 WL, then the requirements for respiratory protection are waived and exposure monitoring can revert to the schedule described starting at section C,1. [Note: A new reference period shall begin at this time, requiring 12 randomly selected sampling days, the first of which is to be coded as i = 1.] This criterion (as discussed in section H,2) serves to provide early confirmation that the corrective steps taken by the mine operator have been effective in limiting the average work shift concentration of radon progeny to a level not exceeding 1.5 times the recommended exposure limit (REL) of 1/12 WL.

5. If $\hat{\alpha}_i$ is $\leq$ 0.14 WL, then: (a) continue collecting seven grab samples on each of the two randomly selected sampling days in each 2-week block of time, and (b) continue using the criteria given in section C. After 12 weeks of sampling in which no two consecutive sampling days ($\hat{\alpha}_i$ and $\hat{\alpha}_{i+1}$) were in excess of 0.14 WL, use the criteria given in section D for assurance, based on 12 days of sampling, that the average work shift concentration of radon progeny is in compliance with the REL, which, if verified, will result in less frequent exposure monitoring requirements.

D. Criteria for Less Frequent Exposure Monitoring

To determine if less frequent exposure monitoring can be conducted at a specific work area, the following statistical decision criteria must be used:

1. Compute $\hat{\alpha}_{\bullet}$ (the estimated average work shift concentration using seven grab samples per sampling day) for a work area during the reference period in which 12 samples were taken and no two consecutive sampling days ($\hat{\alpha}_i$ and $\hat{\alpha}_{i+1}$) were in excess of 0.14 WL. Formulae for this computation are contained in section G.

2. Compute LCL and UCL, the 95% one-sided lower and 95% one-sided upper confidence limits, respectively, for the average work shift concentration during the reference period from which the 12 sampling days were taken. Formulae for these computations are contained in section G; $\hat{\alpha}_{\bullet}$ from section D,1 is a quantity used in the formulae for LCL and UCL.

3. The block length can be increased from 2 weeks to 26 weeks (therefore requiring only 2 randomly selected sampling days per 26-week block of time) if both of the following results occur at a station: (a) UCL (for the average work shift concentration during the 12-week period) is $\leq$ 1/12 WL, and (b) the estimated average work shift concentrations on any two consecutive randomly selected sampling days ($\hat{\alpha}_i$ and $\hat{\alpha}_{i+1}$) within the same reference period did not exceed 0.14 WL. Criteria for the continuation of less frequent exposure monitoring and for the cessation of exposure monitoring are given in parts E and F, respectively.

4. If LCL exceeds 1/12 WL, then: (a) steps shall be taken to reduce the radon progeny concentration in that work area by implementing work practices and engineering controls, (b) respiratory protection shall be required for all miners entering that work area, and (c) grab sampling as described in section C,2 shall be conducted on a consecutive daily basis.

Grab sampling shall continue on a consecutive daily basis until the estimated average work shift concentrations on any two consecutive workdays ($\hat{\alpha}_A$ and $\hat{\alpha}_B$) are both $\leq$ 0.10 WL. When $\hat{\alpha}_A$ and $\hat{\alpha}_B$ are both $\leq$ 0.10 WL, then the requirements for respiratory protection are waived and exposure monitoring can revert to the schedule described starting at section C,1. [Note: A new reference period shall begin at this time, requiring 12 randomly selected sampling days, the first of which is to be coded as $i = 1$.]

E. Criteria for Continuation of Less Frequent Exposure Monitoring

After completion of two additional sampling days during the subsequent 26-week period, the data from the last 12 days sampled must be used to compute a new UCL for the period in which the 12 sampling days occurred.

1. Sampling may continue under the less frequent sampling schedule (i.e., 2 days per 26-week block of time) if both of the following results occur at a station: (a) UCL for the reference period from which the last 12 sampling days were taken is $\leq$ 1/12 WL, and (b) the estimated average work shift concentrations on the last two of the 12 sampling days ($\hat{\alpha}_{11}$ and $\hat{\alpha}_{12}$) were both $\leq$ 0.14 WL. In this case, an updated UCL shall be recomputed after completion of sampling in each subsequent 26-week block of time to determine if less frequent sampling (i.e., on two days during a 26-week period) should be continued according to the criteria of this part. If either of these conditions are not met, then LCL must be computed from data obtained from the last 12 days sampled (see section E,2 which follows).

2. If LCL for the reference period from which the 12 sampling days were taken at a station exceeds 1/12 WL, then: (a) steps shall be taken to reduce the radon progeny concentration in that work area by implementing work practices and engineering controls, (b) respiratory protection shall be required for all miners entering that work area, and (c) grab sampling as described in section C,2 shall be conducted on a consecutive daily basis.

   Grab sampling shall continue on a consecutive daily basis until the estimated average work shift concentrations on any two consecutive workdays ($\hat{\alpha}_A$ and $\hat{\alpha}_B$) are both $\leq$ 0.10 WL. When $\hat{\alpha}_A$ and $\hat{\alpha}_B$ are both $\leq$ 0.10 WL, then the requirements for respiratory protection are waived and exposure monitoring can revert to the schedule described starting at section C,1.

3. If LCL for the reference period from which the 12 sampling days were randomly taken is $\leq$ 1/12 WL, but the estimated average work shift concentration determined for either of the last two of the 12 sampling days ($\hat{\alpha}_{11}$ or $\hat{\alpha}_{12}$) exceeds 0.14 WL, then monitoring at that station shall return to the more frequent sampling schedule (2 days per 2-week block of time). In this case, $\hat{\alpha}_{11}$ or $\hat{\alpha}_{12}$ becomes $\hat{\alpha}_A$ and sampling is required on the next workday to obtain $\hat{\alpha}_B$, as described starting at section C,4,a.

F. Criteria for Cessation of Exposure Monitoring

Sampling can be discontinued at a station if both of the following results occur at that station: (1) UCL for the reference period from which 12 sampling days were taken is $\leq$ 0.063 WL, and (2) the estimated average work shift concentration for the last of the 12 sampling days ($\hat{\alpha}_{12}$) is $\leq$ 0.033 WL. However, sampling should return to the regular schedule, as described starting at section C,1 if an environmental change or a change in mining operations occurs that may alter radon progeny concentrations in that work area.

G. Statistical Considerations and Data Analysis Formulae

The following are the statistical notations used in the sampling strategy:

c_{ij} = measured concentration of radon progeny in the jth grab sample taken on the ith sampling day, where $j = 1,2,\ldots,7$ for each day and $i = 1,2,\ldots,12$ (2 workdays selected at random from each of six consecutive blocks of time).

c_{Aj} = measured concentration of radon progeny in the jth grab sample taken on day A, where $j = 1,2,\ldots,7$.

c_{Bj} = measured concentration of radon progeny in the jth grab sample taken on the next workday following day A, where $j = 1,2,\ldots,7$.

x_{ij} = natural logarithm of $c_{ij} = \ln c_{ij}$

x_{Aj} = natural logarithm of $c_{Aj} = \ln c_{Aj}$

x_{Bj} = natural logarithm of $c_{Bj} = \ln c_{Bj}$

$\bar{x}_i$ = average of the 7 x_{ij} values for the 7 grab samples taken on day i.

$$= (1/7) \sum_{j=1}^{7} x_{ij}$$

$\bar{x}_\bullet$ = average of the 12 $\bar{x}_i$ values during the reference period from which 12 sampling days were randomly selected.

$$= (1/12) \sum_{i=1}^{12} x_i$$

$\bar{x}_A$ = average of the 7 x_{Aj} values for the 7 grab samples taken on day A.

$$= (1/7) \sum_{j=1}^{7} x_{Aj}$$

$\bar{x}_B$ = average of the 7 x_{Bj} values for the 7 grab samples taken on day B, where day B is the next workday following day A.

$$= (1/7) \sum_{j=1}^{7} x_{Bj}$$

$\bar{x}_{11}$ = average of the 7 $x_{11,j}$ values (natural logarithms) for the 7 grab samples taken on the 11th of the 12 randomly selected sampling days in the reference period.

$$= (1/7) \sum_{j=1}^{7} x_{11,j}$$

$\bar{x}_{12}$ = average of the 7 $x_{12,j}$ values (natural logarithms) for the 7 grab samples taken on the last of the 12 randomly selected sampling days in the reference period.

$$= (1/7) \sum_{j=1}^{7} x_{12,j}$$

s_L = standard deviation (of daily averages of logarithms) computed from the 12 x_i's for the 12 days sampled during the reference period.

$$= [(1/11) \sum_{i=1}^{12} (\bar{x}_i - \bar{x}_\bullet)^2]^{(1/2)}$$

$\alpha_\bullet$ = long-term average work shift concentration during the reference period from which 12 sampling days were randomly selected.

$\hat{\alpha}_\bullet$ = estimate of $\alpha_\bullet$ (based on <u>seven</u> grab samples per sampling day) during the reference period from which 12 sampling days were randomly selected.
= $\exp [\bar{x}_\bullet + 0.5\, s_L{}^2]$

LCL = 95% one-sided lower confidence limit for $\alpha_\bullet$
= $\hat{\alpha}_\bullet/[1+1.796\, s_L\, (0.1 + 0.05\, s_L{}^2)^{(1/2)}]$

UCL = 95% one-sided upper confidence limit for $\alpha_\bullet$
= $\hat{\alpha}_\bullet/[1-1.796\, s_L\, (0.1 + 0.05\, s_L{}^2)^{(1/2)}]$

α_i = average work shift concentration for day i, where i = 1,2,...,12 and day i is the i<u>th</u> day in a time-ordered sequence of the 12 days that were randomly selected from the reference period.

$\hat{\alpha}_i$ = estimate of α_i (based on <u>seven</u> grab samples), where i = 1,2,...,12 and day i is the i<u>th</u> day in a time-ordered sequence of the 12 days that were randomly selected from the reference period.
= $\exp [\bar{x}_i + 0.5\, (1 - 1/7)\, \ln^2(1.3335)] = 1.036 \exp [\bar{x}_i]$

$\hat{\alpha}_{i+1}$ = estimated average work shift concentration for day i+1 (based on <u>seven</u> grab samples), where i = 1,2,...,11 and day i+1 is the next sampling day following day i in a time-ordered sequence of the 12 days that were randomly selected from the reference period.
= $\exp [\bar{x}_{i+1} + 0.5\, (1 - 1/7)\, \ln^2(1.3335)] = 1.036 \exp [\bar{x}_{i+1}]$

$\hat{\alpha}_A$ = estimated average work shift concentration for day A (based on <u>seven</u> grab samples), where "day A" is a term used to designate one of the 12 randomly selected days sampled during the reference period for which the α_i value is in a critical range.
= $\exp [\bar{x}_A + 0.5\, (1 - 1/7)\, \ln^2(1.3335)] = 1.036 \exp [\bar{x}_A]$

$\hat{\alpha}_B$ = estimated average work shift concentration for day B (based on seven grab samples), where day B is the first workday following day A. [Note: Day B may or may not be the next calendar day after day A since a weekend, holiday, or other non-workday may occur between days A and B.]
= $\exp[\bar{x}_B + 0.5\ (1 - 1/7)\ \ln^2(1.3335)] = 1.036 \exp[\bar{x}_B]$

$\hat{\alpha}_{11}$ = estimated average work shift concentration (based on seven grab samples) on the 11th of the 12 randomly selected days sampled during a reference period.
= $\exp[\bar{x}_{11} + 0.5\ (1 - 1/7)\ \ln^2(1.3335)] = 1.036 \exp[\bar{x}_{11}]$

$\hat{\alpha}_{12}$ = estimated average work shift concentration (based on seven grab samples) on the last of the 12 randomly selected days sampled during a reference period.
= $\exp[\bar{x}_{12} + 0.5\ (1 - 1/7)\ \ln^2(1.3335)] = 1.036 \exp[\bar{x}_{12}]$

H. Rationale for the Critical Points in the Sampling Strategy

NIOSH recognizes that the concentration of radon progeny in any work area varies with time. Therefore, exposure estimates based on one or even several grab samples may not provide an accurate measurement of the average work shift concentration. Nevertheless, NIOSH believes that by using estimates of radon progeny concentrations determined from grab sampling measurements, it is possible to determine (with at least 95% confidence) that the long-term average work shift concentration would not exceed 1/12 WL by more than a factor of 3.15, based on exposure data derived from seven grab samples taken during a single work shift ($\hat{\alpha}_i$). This factor can be reduced to 1.43 if an estimate of exposure were used based on 12 sampling days ($\hat{\alpha}_\bullet$).

The estimates $\hat{\alpha}_i$, $\hat{\alpha}_A$, and $\hat{\alpha}_B$ for a single work shift's average concentration of radon progeny are based on an assumed log-normal distribution of intraday concentration variations with a geometric standard deviation (GSD) of 1.3335. An assumed log-normal interday distribution with a GSD of 1.3926 was used to calculate critical values of estimates to test hypotheses about the long-term average work shift concentration. The stated GSDs were computed from published historic data on intraday and interday variability of radon progeny concentrations in uranium mines [Johnson 1978]. Other data sets were examined; however, they were not suitable for estimating intraday and interday exposure variabilities that were unaffected by location. The interday and intraday variations in concentrations were modeled as independent log-normal distributions, based on general models for determining occupational exposure concentrations reported elsewhere [Bar-Shalom et al. 1975; Leidel et al. 1975, 1977].

1. Initial Compliance with the REL

Based on analysis of the Johnson [1978] data set, 0.14 WL was calculated to be the 95th percentile of a log-normal model for the distribution of the estimated daily average work shift concentrations ($\hat{\alpha}_i$'s) when the long-term average work shift concentration ($\alpha_\bullet$) was 1/12 WL. Thus when the estimated average work shift concentrations are greater than 0.14 WL on two consecutive workdays, substantial evidence exists that the long-term average work shift concentration exceeds 1/12 WL. Therefore, when $\hat{\alpha}_A$ and $\hat{\alpha}_B$ both exceed 0.14 WL in a work area, NIOSH recommends that radon progeny concentrations be reduced in that work area by implementing work practices and engineering controls, and that the use of respiratory protection be required for all miners entering that work area. These recommendations are also made when the 95% lower confidence limit for the long-term average work shift concentration (LCL) exceeds 1/12 WL (see section D,4).

2. Return to Compliance with the REL

The NIOSH sampling strategy uses criteria with approximately 90% confidence for an initial determination that a work area is tentatively back to compliance with the REL. Specifically, estimated average work shift concentrations from two consecutive workdays (i.e., $\hat{\alpha}_A$ and $\hat{\alpha}_B$) in which both are $\leq$ 0.10 WL was chosen as a criterion that demonstrates reasonable evidence that the average radon progeny concentration is being controlled to $\leq$ 0.125 WL (i.e., 1.5 times the REL). Given the levels of intraday and interday variabilities observed in the Johnson [1978] data set, a work area with an average work shift concentration of 0.125 WL (i.e., 50% above the REL of 1/12 WL) has 0.90 probability to have one or both of a pair of consecutive estimated average work shift concentrations above 0.10 WL.

This "2-day" decision rule limits the magnitude with which a work area's average work shift concentration may exceed 1/12 WL and be undetected. This rule also has the advantage of permitting an early return to normal operations after a period of corrective actions to reduce exposure concentrations, at the expense of having less than high confidence that the REL is not being exceeded by more than 50%. However, only a small proportion of time passes until the next sampling day (as specified in the sampling strategy relative to the year), so that the 2-day rule limits the contribution of a temporarily excessive exposure in a work area to a miner's cumulative annual exposure. At a later time, the lower confidence limit criterion for noncompliance determined after 12 randomly selected sampling days (i.e., LCL > 1/12 WL) would be likely to detect a statistically significant increase above the REL if the long-term average work shift concentration were as high as 0.125 WL.

3. Less Frequent Exposure Monitoring

The upper confidence limit criterion (i.e., UCL $\leq$ 1/12 WL) gives 95% confidence that the long-term average work shift concentration is not above 1/12 WL, under the assumption that $\hat{\alpha}_i$'s exhibit log-normally distributed random variations. The additional requirement that $\hat{\alpha}_i$ and $\hat{\alpha}_{i+1}$ do not exceed 0.14 WL is meant to detect a temporarily or periodically high average work shift concentration (i.e., high $\hat{\alpha}_i$'s that are not sustained for the full block of time from which 12 sampling days were selected). When both of these requirements are met, only 2 randomly selected sampling days are then required per 26-week block of time.

4. Cessation of Exposure Monitoring

UCL$\leq$ 0.063 WL gives greater than 95% confidence that the long-term average work shift concentration ($\alpha_{\bullet}$) is $\leq$ 0.063 WL (i.e., $\alpha_{\bullet}$ is no larger than 75% of the REL), under the assumption that $\hat{\alpha}_i$'s exhibit log-normally distributed random variations. Under the additional assumption that geometric standard deviations (GSDs) for intraday and interday (log-normal) variability are similar to those reported in Johnson [1978], the criterion that $\hat{\alpha}_{12}$ (the estimated average work shift concentration on the last of the 12 sampling days) be $\leq$ 0.033 WL gives 95% confidence that a projected future reference period would have a long-term average work shift concentration $\leq$ 0.063 WL.

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APPENDIX V

MEDICAL ASPECTS OF WEARING RESPIRATORS*

In recommending medical evaluation criteria for respirator use, one should apply rigorous decision-making principles [Halperin et al. 1986]; tests used should be chosen for operating characteristics such as sensitivity, specificity, and predictive value. Unfortunately, many knowledge gaps exist in this area. The problem is complicated by the large variety of respirators, their conditions of use, and individual differences in the physiologic and psychologic responses to them. For these reasons, the following guidelines are to be considered as informed suggestions rather than established NIOSH policy recommendations. They are intended primarily to assist the physician in developing medical evaluation criteria for respirator use.

A. Background Information

Brief descriptions of the health effects associated with wearing respirators are summarized below. More detailed analyses of the data are available in recent reviews by James [1977] and Raven et al. [1979].

1. Pulmonary Effects

In general, the added inspiratory and expiratory resistances and dead space of most respirators cause an increase in tidal volume and a decrease in respiratory rate and ventilation (including a small decrease in alveolar ventilation). These respirator effects have usually been small both among healthy individuals and, in limited studies, among individuals with impaired lung function [Gee et al. 1968; Altose et al. 1977; Raven et al. 1981; Hodous et al. 1983; Hodous et al. 1986]. This generalization is applicable to most respirators when resistances (particularly expiratory resistance) are low [Bentley et al. 1973; Love et al. 1977]. While most studies report minimal physiologic effects during submaximal exercise, the resistances commonly lead to reduced endurance and reduced maximal exercise performance [Craig et al. 1970; Raven et al. 1977; Stemler and Craig 1977; Myhre et al. 1979; Deno et al. 1981]. The dead space of a respirator (reflecting the amount of expired air that must be rebreathed before fresh air is obtained) tends to cause increased ventilation. At least one study has shown substantially increased ventilation with a full-face respirator, a type that can have a large effective dead space [James et al. 1984]. However, the net effect of a respirator's added resistances and dead space is usually a small decrease in ventilation [Craig et al. 1970; Hermansen et al. 1972; Raven et al. 1977; Stemler and Craig 1977; Deno et al. 1981; Hodous et al. 1983].

The potential for adverse effects, particularly decreased cardiac output, from the positive pressure feature of some respirators has been

*Adapted from NIOSH Respiratory Decision Logic [NIOSH 1987].

reported [Meyer et al. 1975]. However, several recent studies suggest that this is not a practical concern, at least not in healthy individuals [Bjurstedt et al. 1979; Arborelius et al. 1983; Dahlback and Balldin 1984].

Theoretically, the increased fluctuations in thoracic pressure caused by breathing with a respirator might constitute an increased risk to subjects with a history of spontaneous pneumothorax. Few data are available in this area. While an individual is using a negative-pressure respirator with relatively high resistance during very heavy exercise, the usual maximal-peak negative oral pressure during inhalation is about 15-17 cm of water [Dahlback and Balldin 1984]. Similarly, the usual maximal-peak positive oral pressure during exhalation is about 15-17 cm of water, which might occur with a respirator in a positive-pressure mode, again during very heavy exercise [Dahlback and Balldin 1984]. By comparison, maximal positive pressures such as those during a vigorous cough can generate 200 cm of water pressure [Black and Hyatt 1969]. The normal maximal negative pleural pressure at full inspiration is -40 cm of water [Bates et al. 1971], and normal subjects can generate -80 to -160 cm of negative water pressure [Black and Hyatt 1969]. Thus while vigorous exercise with a respirator does alter pleural pressures, the risk of barotrauma would seem to be substantially less than that of coughing.

In some asthmatics, an asthmatic attack may be exacerbated or induced by a variety of factors including exercise, cold air, and stress, all of which may be associated with wearing a respirator. While most asthmatics who are able to control their condition should not have problems with respirators, a physician's judgment and a field trial may be needed in selected cases.

2. Cardiac Effects

The added work of breathing from respirators is small and could not be detected in several studies [Gee et al. 1968; Hodous et al. 1983]. A typical respirator might double the work of breathing (from 3% to 6% of the total oxygen consumption), but this is probably not of clinical significance [Gee et al. 1968]. In concordance with this view, several other studies indicated that at the same workloads heart rate does not change with the wearing of a respirator [Raven et al. 1982; Harber et al. 1982; Hodous et al. 1983; Arborelius et al. 1983; Petsonk et al. 1983].

In contrast, the added cardiac stress due to the weight of a heavy respirator may be considerable. A self-contained breathing apparatus (SCBA) may weigh up to 35 pounds. Heavier respirators can reduce maximum external workloads by 20% and similarly increase heart rate at a given submaximal workload [Raven et al. 1977]. In addition, it should be noted that many uses of SCBA (e.g., for firefighting and hazardous waste site work) also necessitate the wearing of 10-25 pounds of protective clothing.

Raven et al. [1982] found statistically significant higher systolic and/or diastolic blood pressures during exercise for persons wearing respirators. Arborelius et al. [1983] did not find significant differences for persons wearing respirators during exercise.

3. Body Temperature Effects

Proper regulation of body temperature is primarily of concern with the closed circuit SCBA that produces oxygen via an exothermic chemical reaction. Inspired air within these respirators may reach 120°F (49°C), thus depriving the wearer of a minor cooling mechanism and causing discomfort. Obviously this can be more of a problem with heavy exercise and when ambient conditions and/or protective clothing further reduce the body's ability to lose heat. The increase in heart rate because of increasing temperature represents an additional cardiac stress.

Closed-circuit breathing units of any type have the potential for causing heat stress since warm expired gases (after exothermic carbon dioxide removal with or without oxygen addition) are rebreathed. Respirators with large dead spaces also have this potential problem, again because of partial rebreathing of warmed expired air [James et al. 1984].

4. Sensory Effects

Respirators may reduce visual fields, decrease voice clarity and loudness, and decrease hearing ability. Besides the potential for reduced productivity, these effects may result in reduced industrial safety. These factors may also contribute to a general feeling of stress [Morgan 1983a].

5. Psychologic Effects

This important topic is discussed in recent reviews by Morgan [Morgan 1983a, 1983b]. There is little doubt that virtually everyone suffers some discomfort when wearing a respirator. The large variability and the subjective nature of the psycho-physiologic aspects of wearing a respirator, however, make studies and specific recommendations difficult. Fit testing obviously serves an important additional function by providing a trial to determine if the wearer can psychologically tolerate the respirator. The great majority of workers can tolerate respirators, and experience in wearing them aids in this tolerance [Morgan 1983b]. However, some individuals are likely to remain psychologically unfit for wearing respirators.

6. Local Irritation Effects

Allergic skin reactions may occur occasionally from wearing a respirator, and skin occlusion may cause irritation or exacerbation of preexisting conditions such as pseudofolliculitis barbae. Facial discomfort from the pressure of the mask may occur, particularly when the fit is unsatisfactory.

7. Miscellaneous Health Effects

In addition to the health effects (described above) associated with wearing respirators, specific groups of respirator wearers may be affected by the following factors:

a. Perforated Tympanic Membrane

While inhalation of toxic materials through a perforated tympanic membrane (ear drum) is possible, recent evidence indicates that the airflow would be minimal and rarely if ever of clinical importance [Cantekin et al. 1979; Ronk and White 1985]. In highly toxic or unknown atmospheres, use of positive pressure respirators should ensure adequate protection [Ronk and White 1985].

b. Contact Lenses

Contact lenses are generally not recommended for use with respirators, although little documented evidence exists to support this viewpoint [daRoza and Weaver 1985]. Several possible reasons for this recommendation are noted below:

(1) Corneal Irritation or Abrasion

Corneal irritation or abrasion might occur with the exposure. This would, of course, be a problem primarily with quarter- and half-face masks, especially with particulate exposures. However, exposures could occur with full-face respirators because of leaks or inadvisable removal of the respirator for any reason. While corneal irritation or abrasion might also occur without contact lenses, their presence is known to substantially increase this risk.

(2) Loss or Misplacement of a Contact Lens

The loss or misplacement of a contact lens by an individual wearing a respirator might prompt the wearer to remove the respirator, thereby resulting in exposure to the hazard as well as to the potential problems noted above.

(3) Eye Irritation from Respirator Airflow

The constant airflow of some respirators, such as powered air-purifying respirators (PAPR's) or continuous flow air-line respirators, might irritate the eyes of a contact lens wearer.

B. Suggested Medical Evaluation and Criteria for Respirator Use

The following NIOSH recommendations allow latitude for the physician in determining a medical evaluation for a specific situation. More specific guidelines may become available as knowledge increases regarding human stresses from the complex interactions of worker health status, respirator usage, and job tasks. While some of the following recommendations should be part of any medical evaluation of workers who wear respirators, others are applicable for specific situations.

- A physician should determine fitness to wear a respirator by considering the worker's health, the type of respirator, and the conditions of respirator use.

The recommendation above leaves the final decision of an individual's fitness to wear a respirator to the person who is best qualified to evaluate the multiple clinical and other variables. Much of the clinical and other data could be gathered by other personnel. It should be emphasized that the clinical examination alone is only one part of the fitness determination. Collaboration with foremen, industrial hygienists, and others may often be needed to better assess the work conditions and other factors that affect an individual's fitness to wear a respirator.

- A medical history and at least a limited physical examination are recommended.

The medical history and physical examination should emphasize the evaluation of the cardiopulmonary system and should elicit any history of respirator use. The history is an important tool in medical diagnosis and can be used to detect most problems that might require further evaluation. Objectives of the physical examination should be to confirm the clinical impression based on the history and to detect important medical conditions (such as hypertension) that may be essentially asymptomatic.

- While chest X-ray and/or spirometry may be medically indicated in some fitness determinations, these should not be routinely performed.

In most cases, the hazardous situations requiring the wearing of respirators will also mandate periodic chest X-rays and/or spirometry for exposed workers. When such information is available, it should be used in the determination of fitness to wear respirators.

Data from routine chest X-rays and spirometry are not recommended solely for determining if a respirator should be worn. In most cases, with an essentially normal clinical examination (history and physical) these data are unlikely to influence the respirator fitness determination; additionally, the X-ray would be an unnecessary source of radiation exposure to the worker. Chest X-rays in general do not accurately reflect a person's cardiopulmonary physiologic status, and limited studies suggest that mild to moderate impairment detected by spirometry would not preclude the wearing of respirators in most cases. Thus it is recommended that chest X-rays and/or spirometry be done only when clinically indicated.

- The recommended periodicity of medical fitness determinations varies according to several factors but could be as infrequent as every 5 years.

Federal or other applicable regulations shall be followed regarding the frequency of respirator fitness determinations. The guidelines for most work conditions for which respirators are required are shown in Table V-1.

These guidelines are similar to those recommended by ANSI, which recommends annual determinations after age 45 [ANSI 1984]. The more frequent examinations with advancing age relate to the increased prevalence of most diseases in older people. More frequent examinations are recommended for individuals performing strenuous work involving the use of a SCBA. These guidelines are based on clinical judgment and, like the other recommendations in this section, should be adjusted as clinically indicated.

- The respirator wearer should be observed during a trial period to evaluate potential physiological problems.

In addition to considering the physical effects of wearing respirators, the physician should determine if wearing a given respirator would cause extreme anxiety or claustrophobic reaction in the individual. This could be done during training while the worker is wearing the respirator and is engaged in some exercise that approximates the actual work situation.

Present OSHA regulations state that a worker should be provided the opportunity to wear the respirator "in normal air for a long familiarity period..." [29 CFR 1910.134(e)(5)].* This trial period should also be used to evaluate the ability and tolerance of the worker to wear the respirator [Harber 1984]. This trial period need not be associated with respirator fit testing and should not compromise the effectiveness of the vital fit testing procedure.

Table V-1.--Suggested frequency of medical fitness determinations*

Type of working conditions	Worker age (years)		
	<35	35 - 45	>45
Most work conditions requiring respirators	Every 5 years	Every 2 years	1-2 years
Strenuous working conditions with a SCBA†	Every 3 years	Every 18 months	Annually

*Interim testing would be needed if changes in health status occur.
†SCBA = self-contained breathing apparatus.

*CFR = Code of Federal Regulations. See CFR in references.

- Examining physicians should realize that the main stress of heavy exercise while using a respirator is usually on the cardiovascular system and that heavy respirators (e.g., SCBA) can substantially increase this stress. Accordingly, physicians may want to consider exercise stress tests with electrocardiographic monitoring when heavy respirators are used, when cardiovascular risk factors are present, or when extremely stressful conditions are expected.

Some respirators may weigh up to 35 pounds and may increase workloads by 20 percent. Although a lower activity level could compensate for this added stress [Manning and Griggs 1983], a lower activity level might not always be possible. Physicians should also be aware of other added stresses, such as heavy protective clothing and intense ambient heat, that would increase the worker's cardiac demand. As an extreme example, firefighters who use a SCBA inside burning buildings may work at maximal exercise levels under life-threatening conditions. In such cases, the detection of occult cardiac disease, which might manifest itself during heavy stress, may be important. Some authors have either recommended stress testing [Kilbom 1980] or at least its consideration in the fitness determination [ANSI 1984]. Kilbom [1980] has recommended stress testing at 5-year intervals for firefighters below age 40 who use SCBA and at 2-year intervals for those aged 40-50. He further suggested that firemen over age 50 not be allowed to wear SCBA.

Exercise stress testing has not been recommended for medical screening for coronary artery disease in the general population [Weiner et al. 1979; Epstein 1979]. It has an estimated sensitivity and specificity of 78% and 69%, respectively, when the disease is defined by coronary angiography [Weiner et al. 1979; Nicklin and Balaban 1984]. In a recent 6-year prospective study, stress testing to determine the potential for heart attacks indicated a positive predictive value of 27% when the prevalence of disease was 3.5% [Giagnoni et al. 1983; Folli 1984]. While stress testing has limited effectiveness in medical screening, it could detect individuals who may not be able to complete the heavy exercise required in some jobs.

A definitive recommendation regarding exercise stress testing cannot be made at this time. Further research may determine whether this is a useful tool in selected circumstances.

- An important concept is that "general work limitations and restrictions identified for other work activities also shall apply for respirator use" [ANSI 1984].

In many cases, if a worker is physically able to do an assigned job while not wearing a respirator, the worker will in most situations not be at increased risk when performing the same job while wearing a respirator.

- Because of the variability in the types of respirators, work conditions, and workers' health status, many employers may wish to designate categories of fitness to wear respirators, thereby excluding some workers from strenuous work situations involving the wearing of respirators.

Depending on the various circumstances, several permissible categories of respirator usage are possible. One conceivable scheme would consist of three overall categories: full respirator use, no respirator use, and limited respirator use including "escape only" respirators. The latter category excludes heavy respirators and strenuous work conditions. Before identifying the conditions that would be used to classify workers into various categories, it is critical that the physician be aware that these conditions have not been validated and are presented only for consideration. The physician should modify the use of these conditions based on actual experience, further research, and individual worker sensitivities. He may also wish to consider the following conditions in selecting or permitting the use of respirators:

--History of spontaneous pneumothorax;

--Claustrophobia/anxiety reaction;

--Use of contact lenses (for some respirators);

--Moderate or severe pulmonary disease;

--Angina pectoris, significant arrhythmias, recent myocardial infarction;

--Symptomatic or uncontrolled hypertension; and

--Advanced age.

Wearing a respirator would probably not play a significant role in causing lung damage such as pneumothorax. However, without good evidence that wearing a respirator would not cause such lung damage, the physician would be prudent to prohibit the individual with a history of spontaneous pneumothorax from wearing a respirator.

Moderate lung disease is defined by the Intermountain Thoracic Society [Kanner and Morris 1975] as being present when the following conditions exist--a forced expiratory volume in one second (FEV_1) divided by the forced vital capacity (FVC) (i.e., FEV_1/FVC) of 0.45 to 0.60, or an FVC of 51% to 65% of the predicted FVC value. Similar arbitrary limits could be set for age and hypertension. It would seem more reasonable, however, to combine several risk factors into an overall estimate of fitness to wear respirators under certain conditions. Here the judgment and clinical experience of the physician are needed. Many impaired workers would even be able to work safely while wearing respirators if they could control their own work pace, including having sufficient time to rest.

C. Conclusion

Individual judgment is needed to determine the factors affecting an individual's fitness to wear a respirator. While many of the preceding guidelines are based on limited evidence, they should provide a useful starting point for a respirator fitness screening program. Further research is needed to validate these and other recommendations currently in use. Of particular interest would be laboratory studies involving physiologically impaired individuals and field studies conducted under actual day-to-day work conditions.

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