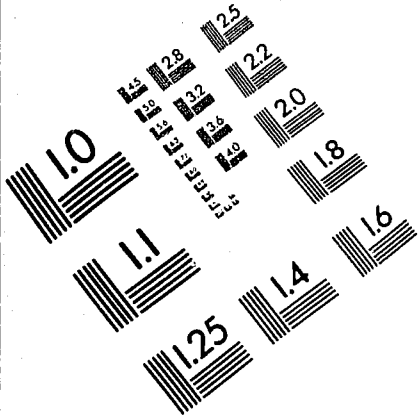
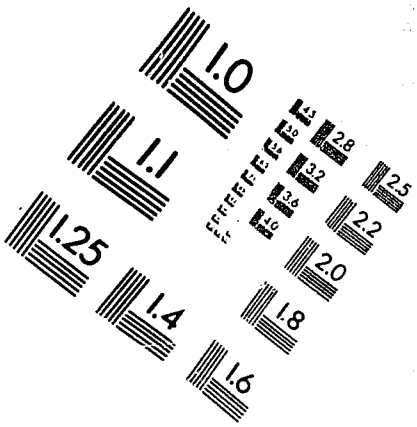
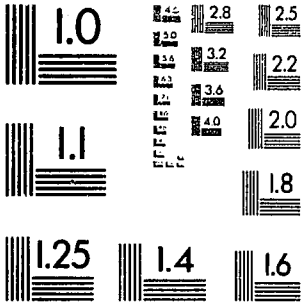
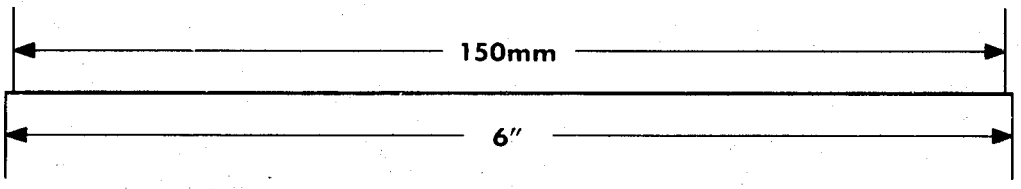
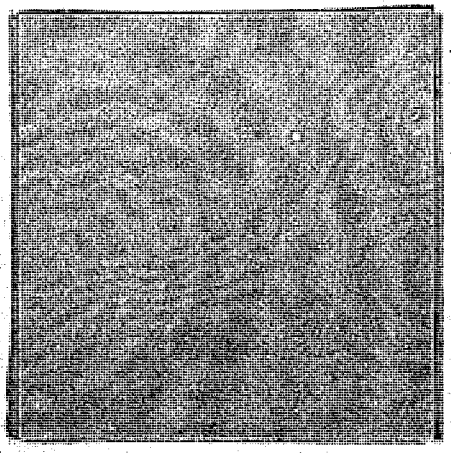
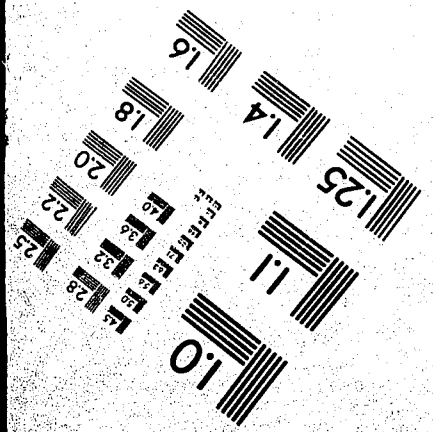

1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0

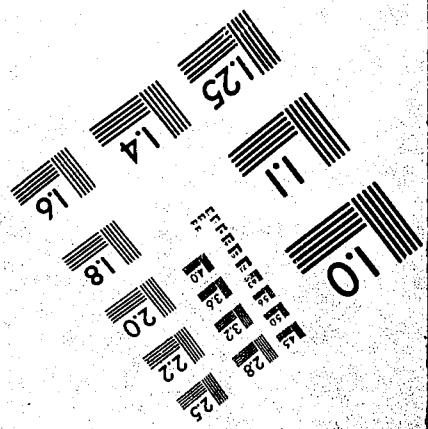

1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0


150mm
6"




1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0

NINA L. TURNER, PHD
THOMAS K. HODOUS, MD

RESPIRATORY PROTECTION IN THE MINING INDUSTRY

From the
Division of Safety Research
National Institute for Occupational Safety and Health
Morgantown, West Virginia

Reprint requests to:
Nina L. Turner, PhD
Division of Safety Research
National Institute for Occupational Safety and Health
Morgantown, WV 26505

Miners are among the several million US workers who currently use respiratory protective devices, or respirators. Since these devices may have adverse effects on an individual, it is important that occupational physicians understand these effects and appropriate respirator use in the mining industry. However, physicians may be relatively unfamiliar with respirators, and few studies have been performed on the effects of respirator wear among workers who have some physiological impairment. The purpose of this chapter is to review relevant regulations, the types of respirators used in the mining industry, and the various effects of their use and to provide reasonable guidelines for determining fitness to wear these devices.

REGULATIONS

The Mine Safety and Health Administration (MSHA) has regulatory authority over virtually all US mining operations. Title 30 (Mineral Resources) of the Code of Federal Regulations contains the applicable regulations in Part 75 (underground coal mines), Part 77 (surface coal operations), Part 56 (surface metal and nonmetal mines, i.e., mines other than coal mines), and Part 57 (underground metal and nonmetal mines).[9]

MSHA has handled the issue of routine exposure of miners to coal and other dusts by requiring increased ventilation within mines, not via the use of personal protective equipment. As long as dust samples show concentrations within acceptable limits, respirator wear during routine mining activities is not required. However, when

dust levels are not in compliance, respirators may be required while improved engineering controls are being put in place. It must also be noted that any mine may have exposures other than to the primary ore and surrounding rock being mined. For example, coal mine workers may be exposed to coal tar pitch volatiles from creosoted timbers, to polyurethane resins used in some roof support systems, and to perchlorethylene and other chemicals in coal analysis laboratories.

Besides the regulatory requirements for potential respirator wear, in some mining operations respirators may be worn electively. Management contracts with the United Mine Workers of America, which are often also followed by nonunionized coal-mining operations, stipulate that the company will provide a respirator to any miner who asks for this additional protection (even if the mine is in compliance with federal dust standards). Finally, individual companies may have their own policies regarding respirator wear. Although good statistics are not easily obtained, it is estimated that in long-wall coal mines, approximately 30% of the miners wear (elective) respiratory protection, and that perhaps 10% of miners wear respirators in conventional coal-mining operations.

The general use of respirators for underground and surface coal mines are covered in Parts 75.1720(b) and 77.1710(b) of the regulations, respectively.[9] Although these sections refer to "injury to the skin," MSHA here takes a broad interpretation of "skin" to include the lining of the lungs, thereby including the possible need for respiratory protection. In contrast to the Occupational Safety and Health Administration (OSHA) regulations, MSHA in these rules does not require either a medical examination to determine fitness to wear a respirator or a formal respirator program.

The regulations for metal and nonmetal mines require a respirator program consistent with the "American National Standards Practices for Respiratory Protection,"[3] which recommends a medical evaluation to determine an individual's fitness to wear a respirator.

In addition to the nonemergency use of respirators noted above, all underground mines are required to have respirators available for miners to use to escape from the mine during an emergency situation. These respirators are sometimes referred to as "self-rescuers." Current regulations require that all underground miners have access to a self-contained, self-rescue device that will provide breathing air for 1 hour. Specific training and programs are included in these regulations.

TYPES OF RESPIRATORY PROTECTION

Virtually any type of respirator may be found in use in the mining industry, depending on the exposure and whether the respirator use is elective or mandatory. For further information regarding the protection provided by the various types of respirators and regarding respirator programs, the reader is referred to standard industrial hygiene tests as well as published guidelines.[3] It should be noted that both of the referenced guidelines recommend medical evaluation to determine fitness to wear a respirator, fit tests to help ensure adequate protection by the respirator, proper respirator selection, training, and maintenance procedures. It is believed that without a complete respiratory protection program, workers will not receive the degree of protection anticipated from a respirator.

The most important uses of respirators in the mining industry continue to be escape and rescue activities during emergencies such as fires or explosions. Two basic types of respirators are used for mine escapes. The first is an air-purifying respirator with a canister for protection against gases and vapors (acid gases, carbon

monoxide, organic vapors). These **"escape gas masks"** usually consist of a half-mask facepiece (covering the nose and mouth), weigh about 1.5 lbs, and are compact enough to be worn on a miner's belt. They are designed for escape only from atmospheres that are immediately dangerous to life or health (IDLH) or from non-IDLH atmospheres where there is a short distance to travel, usually from the mining site to an area where a second, more protective type of respirator is stored.

The second device, known as a **self-contained breathing apparatus** (SCBA), provides its own air supply to the user for escape or rescue activities in IDLH atmospheres with potential oxygen deficiency. Escape SCBA devices are used with mouthpieces, full facepieces, or hoods and are usually rated for 3 to 60 minutes of use (as noted above, underground mines must include 60-minute devices for use by all miners). These devices are of a closed-circuit design; they remove carbon dioxide from the expired gas and provide oxygen-enriched inspired gas. Escape devices weigh between 5 and 8 lbs and are currently being redesigned to be belt-wearable. Figure 1 shows several closed-circuit, escape-only SCBAs.

Rescue SCBA devices are used by personnel who enter mines for the purpose of rescuing others. Like the SCBA self-rescuer respirators, they are also usually closed circuit in design, but they weigh between 30 and 39 lbs and are worn on the back with a full facepiece (covering mouth, nose, and eyes). These units are rated for 2 to 4 hours of use and may incorporate a cooling device to lower the temperature of the inspired gas.

MEDICAL ASPECTS OF RESPIRATOR WEAR

Although respirators are used to provide protection to the miner, they also have potential adverse effects which the occupational physician should understand. Many studies have been conducted on the physiologic and psychologic effects of wearing respirators, but many knowledge gaps continue to exist in this area. This problem is due in part to the variety of respirators, their conditions of use, and individual differences in the users' responses to them. The following background information is provided to assist physicians in developing medical evaluation criteria for respirator use in the mining industry. A summary of the effects described below is provided in Table 1.[22]

Pulmonary Effects

Several reviews have described the ventilatory effects of respirator wear.[27,39] In general, the added resistance to breathing and the dead space of closed-circuit SCBAs cause an increase in tidal volume and a decrease in respiratory rate and ventilation. When resistances are low, these respirator effects have been shown to be small among healthy subjects and, in limited studies, among subjects with impaired lung function.[6,16,20,21,29,40] Although most studies report minimal physiologic effects during submaximal exercise, higher resistances lead to reduced endurance and reduced maximal exercise performance due to the limitations placed on ventilation.[5,11,14,34,38,42] These findings are in agreement with the theoretical consideration that physiologic loading and sensations of dyspnea are related to the disproportion between the work of breathing and the actual ventilation that can be produced during inspiratory resistive loading.[5]

While it is generally accepted that added resistance to breathing limits performance, there is still no agreement on an ideal, maximum allowable breathing resistance. Current federal regulations[10] for closed-circuit SCBAs require that the difference between expiratory and inspiratory pressures shall not

FIGURE 1. Two typical closed-circuit self-contained breathing apparatuses (SCBA). (Courtesy US Bureau of Mines.)

exceed 10 cm H_2O and that expiratory pressure shall not exceed 5.1 cm H_2O during a breathing machine test at a ventilation of 40 L/min. However, during heavy exercise, a wearer can experience peak inspiratory and expiratory oral pressures of 15 to 25 cm H_2O.[5] By comparison, maximal pressures during a vigorous cough can be as high as 200 cm H_2O.[22] Thus, although respirator wear might pose an increased risk to wearers predisposed to spontaneous pneumothorax, the risk appears to be substantially less than that of the cough maneuver.

The effect of breathing elevated levels of CO_2 is an increase in ventilation, primarily due to increased tidal volume followed by an increase in respiratory rate.[23] Other effects include decreased mental performance, headaches, and nausea.

TABLE 1. Major Medical Effects of Respirator Wear*

Function/System Affected	Mechanism	Effects
Pulmonary	↑ Resistance	↑ Work of breathing
	↑ Dead space	↓ Ventilation
		↓ Maximal work
Cardiac	↑ Work of breathing	↑ Cardiac work
	Respirator weight	↓ Maximal external work
Temperature	↑ Temperature of inspired air	↑ Body temperature and discomfort
	↓ Relative humidity of hot inspired air	↓ Expired relative humidity
Diminished senses	Partial mask obstruction of visual field	Reduced visual fields
	Covering of mouth	Decreased voice clarity and loudness
	Covering of ears: respirator noises	Decreased hearing
Psychological reaction	Enclosures of face/head	Claustrophobia
		Loss of "habits" (chewing, spitting, blowing nose, scratching, etc.)
	Other effects	↑ Generalized stress
Local irritation	Mask face pressure	Discomfort
	Allergy	Discomfort, rash
	Occlusion of skin	Folliculitis

* Data from Hodous.[22]

Various investigators have proposed maximum allowable CO_2 concentrations for SCBA.[5,28] Current federal regulations for CO_2 concentrations mandate that the maximum average CO_2 concentration be between 1 and 2.5%, depending on the service time of the SCBA during a breathing machine test of an apparatus.[10]

Cardiovascular Effects

Several authors have addressed the influence of SCBA weight on energy expenditure and have found that the added cardiac stress due to a heavy device, such as a rescue SCBA, may be considerable.[26,30,38,44] Respirators weighing approximately 35 lbs have been shown to reduce maximum treadmill workloads by 17 to 30% and similarly increase heart rate for a given submaximal work load.[18,30,38] Cardiac demand increases even further if any type of protective clothing is worn with the respirator.

The added work of breathing due to respirator wear is usually small; a typical respirator might double the work of breathing from 3% to 6% of the oxygen consumption.[16] Several other studies agree with this view, finding that heart rate does not change substantially with respirator wear for a given workload.[2,20,21]

It has been suggested that positive pressure respirators, such as those used in the fire service, may have adverse effects on cardiac output.[2] To provide maximal protection against inward leakage of contaminants, these respirators are designed to maintain positive airway pressure within the facepiece throughout the breathing cycle. However, several studies have demonstrated that positive pressure devices do not decrease cardiac output in healthy subjects.[2,12]

Thermal Effects

Although significant thermal stress is usually the combined result of wearing protective clothing in a hot ambient environment, respirators themselves can impose some degree of heat stress on the wearer. Closed-circuit SCBAs produce

O_2 and remove CO_2 via exothermic chemical reactions, causing inspired air temperatures to approach 50°C (122°F) and relative humidities to be either very low or nearly saturated.

Several studies have addressed the effects of heat stress imposed by respiratory protective devices on physiologic and subjective response.[5,17,31,36,43] During moderate and heavy exercise, these inspired air conditions deprive the wearer of respiratory mechanisms of heat loss and cause discomfort. Figure 2 demonstrates the fall in mean expired relative humidity, due to slight drying of the upper airways, that occurs with hot dry air inhalation during exercise and rest.

Current federal regulations base the maximum allowable inspired air temperatures (dry bulb) on the service life of the apparatus and the relative humidity of the inspired air. The maximum temperatures range from 35°C (95°F) for long-duration rescue units to 57°C (130°F) for 15-minute escape units.[10] Additional research is needed in this area for the further refinement of these inspired air temperature criteria.

Psychological Effects

Psychological factors may affect the likelihood of compliance with proper respirator use and of experiencing discomfort during use. Several recent reviews[32,33] have described the large variability and subjective nature of the psychological aspects of respirator use. Such factors make definitive studies and individual recommendations difficult to achieve. These studies also suggest that psychological testing such as for anxiety trait can often identify those individuals who will not be able to tolerate respirators; however, it is not felt that this evaluation is generally needed.[33]

Fit-testing, an important component of all respirator programs in which the adequacy of the facial seal of a respirator is tested, can serve an important

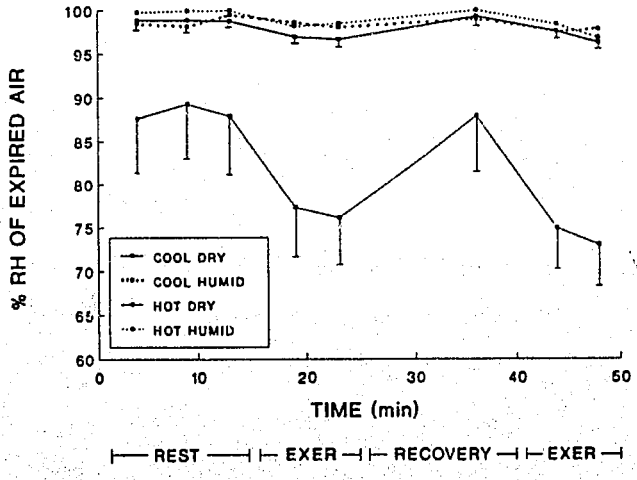


FIGURE 2. **Effects of hot dry and hot humid air breathing on mean expired relative humidity during rest and exercise. From Turner et al.[43]**

additional function in providing an informal basis for determining if the wearer can psychologically tolerate the respirator. Although some individuals will be psychologically unfit for respirator wear, it is generally accepted that the great majority of workers can tolerate respirators and that experience aids in this tolerance.

Other Effects

Several additional respirator–workplace–wearer interactions are noted:

1. **Local Irritation.** Allergic skin reactions may rarely result from respirator wear, and skin occlusion may exacerbate preexisting conditions such as pseudofolliculitis barbae.[22]

2. **Perforated Tympanic Membrane.** Although inhalation of toxic gases through a perforated tympanic membrane (eardrum) is possible, evidence indicates the airflow would be minimal and rarely, if ever, of clinical importance.[7,41]

3. **Contact Lenses.** Contact lenses are sometimes not recommended for use with respirators. Corneal irritation or abrasion might occur with particulate exposures in the absence of goggles or a fullface respirator.[22] The constant airflow of some types of respirators might irritate a contact lens wearer. However, a recent study, based on a survey of firefighters, concluded that contact lens use while wearing a full-facepiece respirator should not be prohibited.[13] Further research is needed to determine whether contact lens use is safe in the different exposure situations.

MEDICAL EVALUATION FOR RESPIRATOR USE

The following recommendations allow latitude for the occupational physician in determining a medical evaluation for a specific situation. They are consistent with the ANSI Z88.2 guidelines which are required for metal and nonmetal mining operations.[3] More specific guidelines will become available as knowledge increases regarding physiologic stresses from the complex interactions of worker health status, respirator usage, and job tasks. In this regard, it should be noted that revised MSHA regulations regarding air quality standards may be expected in 1993.

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. This recommendation leaves the final decision of an individual's fitness to wear a respirator to the person who is best qualified to evaluate 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 evaluation is only one part of the fitness evaluation. Collaboration with foremen, industrial hygienists, and others may often be needed to assess the work conditions 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. A thorough medical history can be used to detect most problems that might require further evaluation. The objectives of the medical examination should be to confirm the clinical impression based on the history and to detect important medical conditions that may be essentially asymptomatic.

Although chest radiography and/or spirometry may be medically indicated in some fitness determinations, these should not be routinely performed. In many

cases, the hazardous situations requiring respirator use will also mandate periodic chest radiographs and/or spirometry for exposed miners. When such information is available, it should be used in the determination of fitness to wear respirators.

Data from routine chest radiographs and spirometry are not recommended as the sole criteria for determining if a respirator can be worn. In most cases, with an essentially normal clinical examination, these data are unlikely to influence the respirator fitness determination. In addition, the radiograph would be an unnecessary source of radiation exposure to the miner. Chest radiographs in general do not adequately reflect a person's cardiopulmonary health, and limited studies suggest that mild to moderate impairment detected by spirometry would not preclude the wearing of respirators in most cases. Therefore, it is recommended that in the determination of fitness to wear a respirator that chest radiographs and/or spirometry be performed 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 should be followed regarding the frequency of respirator fitness determinations. The guidelines for most work conditions for which respirators are required are shown in Table 2.[37] These guidelines are similar to those recommended by ANSI, which recommends annual determinations after age 45.[4] The more frequent examinations with advancing age are related to the increased prevalence of most diseases in older people. More frequent examinations are recommended for individuals who must perform strenuous work while wearing an SCBA. These guidelines are based on clinical judgment and should be adjusted as clinically indicated in individual cases.

The respirator wearer should be observed during a trial period to evaluate potential physiologic 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 miner is wearing the respirator and is engaged in some exercise that approximates the actual work situation. Although not legally applicable to the mining industry, present OSHA regulations state that a worker should be provided the opportunity to wear the respirator in normal air for a long familiarity period.[8] This trial period should also be used to evaluate the tolerance of the worker to wear the respirator. This trial period need not be associated with respirator fit-testing and should not compromise the effectiveness of the fit-testing procedure.

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 can substantially increase this stress. Accordingly, physicians may want to consider exercise stress tests with electrocardiographic monitoring when heavy

TABLE 2. Suggested Frequency of Fitness Determinations*

	Employee Age (yr)		
	<35	35–45	>45
Most work conditions requiring respirator	Every 5 yr	Every 2 yr	1–2 yr
Strenuous work conditions with self-contained breathing apparatus	Every 3 yr	Every 2 yr	Annually

* Interim testing would be needed if changes in health status occur. Data from NIOSH.[37]

respirators are used, when cardiovascular risk factors are present, or when extremely stressful conditions are expected.

Some respirators may weigh 35 to 40 lbs and may increase workloads by 20 to 25%.[38] Although a lower activity level could compensate for this added stress, a lower activity level may 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.[19,24] In cases where near-maximal exercise levels are required, the detection of occult cardiac disease would be important. Some authors have either recommended stress testing or at least its consideration in the fitness determination.[37] Kilbom[25] has recommended stress testing at 5-year intervals for firefighters below age 40 who use SCBAs and at 2-year intervals for those aged 40 to 50. She further suggested that firefighters over age 50 not be allowed to use SCBAs.

Exercise stress testing has not been recommended for medical screening for coronary artery disease in the general population.[15,45] It has an estimated sensitivity and specificity of 78% and 69%, respectively, when the disease is defined by coronary angiography.[35,45] Although stress testing has somewhat limited effectiveness in medical screening, it could detect miners who may not be able to complete the heavy exercise required in some mining jobs (notably mine rescue work using heavy SCBA). A definitive recommendation regarding exercise stress testing cannot be made at this time; further research may determine the usefulness of this 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.[4] In many cases, if a miner is physically able to do an assigned job while not wearing a respirator, the miner will not be at increased risk when performing the same job while wearing a respirator. In this regard, virtually all companies make an assessment of a potential miner's fitness for duty at the time of hire.

Because of the variability in the types of respirators, work conditions, and miners' health status, many employers may wish to designate categories of fitness to wear respirators, thereby excluding some miners from strenuous work situations involving the use of respirators. In the mine setting, this may be confined primarily to selection of mine rescue team members.

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 miners 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:

1. Claustrophobia/anxiety reaction
2. Use of contact lenses (for some respirators)
3. Moderate or severe pulmonary disease
4. Angina pectoris, significant arrhythmias, recent myocardial infarction
5. Symptomatic or uncontrolled hypertension
6. Advanced age

Moderate lung disease can be defined as being present when the following conditions exist: a forced expiratory volume in 1 sec (FEV_1) divided by the forced vital capacity (FVC) (i.e., FEV_1/FVC) below the fifth percentile of a normal population value, and an FEV_1 or FVC from 60 to 69% of the predicted value.[1] 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 circumstances. 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 have sufficient time to rest and control their own work pace.

CONCLUSION

A variety of respirators are commonly used in the mining industry, and legal requirements vary according to the type (coal vs metal and nonmetal) and location (underground vs surface) of the mining operation. New federal mining regulations are likely to be promulgated in the near future, which may mandate new or different programs. The occupational physician should consider these and other factors in deciding how to manage an overall respirator program designed to protect miners.

Individual judgment is needed to determine the factors affecting an individual's fitness to wear a respirator. Although 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.

ACKNOWLEDGMENT

The authors thank Mr. John Dower for his substantial assistance in the preparation of this manuscript.

REFERENCES

1. American Thoracic Society: Lung function testing: Selection of reference values and interpretative strategies. Am Rev Respir Dis 144:1202–1218, 1991.
2. Arborelius M, Dahlback GO, Data PG: Cardiac output and gas exchange during heavy exercise with a positive pressure respiratory protective apparatus. Scand J Work Environ Health 9:471–477, 1983.
3. ANSI Z88.2–1969: American National Standard: Practices for Respiratory Protection. New York, American National Standards Institute, 1969 [also 1980 revision].
4. ANSI Z88.6–1984: American National Standard for Respirator Protection–Respirator Use–Physical Qualifications for Personnel. New York, American National Standards Institute, 1984, pp 7–15.
5. Babb T, Turner N, Saupe K, Pawelczyck J: Physical performance during combinations of hypercapnic, resistive, and hot air breathing. Am Ind Hyg Assoc J 50:105–111, 1989.
6. Bentley RA, Griffin OG, Love RG, et al: Acceptable levels for breathing resistance of respiratory apparatus. Arch Environ Health 27:273–280, 1973.
7. Cantekin EI, Bluestone CD, Saez CA, et al: Airflow through the eustachian tube. Ann Otol 88:603–612, 1979.
8. CFR Code of Federal Regulations, Title 29, Part 1910.134(e)(5). Washington, DC, US Government Printing Office, Office of the Federal Register, 1980.
9. CFR Code of Federal Regulations, Title 30, Mineral Resources, Washington, DC, US Government Printing Office, Office of the Federal Register, 1980.
10. CFR Code of Federal Regulations, Title 30, Mineral Resources, Part 11. Washington, DC, US Government Printing Office, Office of the Federal Register, 1980.

11. Craig FN, Blevins WV, Cummings G: Exhausting work limited by external resistance and inhalation of carbon dioxide. J Appl Physiol 29:847–851, 1970.
12. Dahlback GO, Balldin UI: Physiological effects of pressure demand masks during heavy exercise. Am Ind Hyg Assoc J 45:177–181, 1984.
13. daRoza RA, Weaver C: Is it safe to wear contact lenses with a full-facepiece respirator? Livermore, CA, Lawrence Livermore National Laboratory, 1985, pp 1-3 [manuscript UCRL-53653].
14. Deno NS, Kamon E, Kiser DM: Physiological responses to resistance breathing during short and prolonged exercise. Am Ind Hyg Assoc J 42:616–623, 1981.
15. Epstein SE: Limitations of electrocardiographic exercise testing. N Engl J Med 301:264-265, 1979.
16. Gee JBL, Burton G, Vassallo C, Gregg J: Effects of external airway obstruction on work capacity and pulmonary gas exchange. Am Rev Respir Dis 98:1003–1012, 1968.
17. Gwosdow AR, Nielson R, Berglund LG, et al: Effect of thermal conditions on the acceptability of respiratory protective devices on humans at rest. Am Ind Hyg Assoc J 50:188–195, 1989.
18. Harber P, Tamimie RJ, Bhattacharya A, Barber M: Physiologic effects of respirator dead space and resistance loading. J Occup Med 24:681–684, 1982.
19. Harber P: Medical evaluation for respirator use. J Occup Med 26:496–502, 1984.
20. Hodous TK, Petsonk L, Boyles C, et al: Effects of added resistance to breathing during exercise in obstructive lung disease. Am Rev Respir Dis 128:943–948, 1983.
21. Hodous TK, Boyles C, Hankinson J: Effects of industrial respirator wear during exercise in subjects with restrictive lung disease. Am Ind Hyg Assoc J 47:176–180, 1986.
22. Hodous TK: Screening prospective workers for the ability to use respirators. J Occup Med 28:1074–1080, 1986.
23. James RH: Breathing Resistance and Dead Space in Respiratory Protective Devices. Cincinnati, National Institute for Occupational Safety and Health, 1977 [DHEW (NIOSH) publ no. 77–161].
24. James R, Dukes-Dobos F, Smith R: Effects of respirators under heat/work conditions. Am Ind Hyg Assoc J 45:399–404, 1984.
25. Kilbom A: Physical work capacity of firemen. Scand J Work Environ Health 6:48–57, 1980.
26. Louhevaara VA, Smolander J, Tuomi T, et al: Effects of an SCBA on breathing pattern, gas exchange, and heart rate during exercise. J Occup Med 27:212–216, 1985.
27. Louhevaara VA: Physiological effects associated with the use of respiratory protective devices: A review. Scand J Work Environ Health 10:275–281, 1984.
28. Love RG, Muir DCF, Sweetland KF, et al: Tolerance and ventilatory response to inhaled CO_2 during exercise and with inspiratory resistive loading. Ann Occup Hyg 22:43–53, 1979.
29. Love RG, Muir DCF, Sweetland KF, et al: Acceptable levels for the breathing resistance of respiratory apparatus: Results for men over the age of 45. Br J Ind Med 34:126–129, 1977.
30. Manning JE, Griggs TR: Heart rates in firefighters using light and heavy breathing equipment: Similar near-maximal exertion in response to multiple work load conditions. J Occup Med 25:215–218, 1983.
31. McCutchan JW, Taylor CL: Respiratory heat exchange with varying temperature and humidity of inspired air. J Appl Physiol 4:121–135, 1951.
32. Morgan WP: Psychological problems associated with the wearing of industrial respirators: A review. Am Ind Hyg Assoc J 44:671–676, 1983.
33. Morgan WP: Psychological problems associated with the wearing of industrial respirators. J Int Soc Respir Prot 1:67–108, 1983.
34. Myhre LG, Hoden RD, Baumgardner FW, Tucker D: Physiological limits of firefighters. Brooks AFB, TX, Air Force School of Aerospace Medicine, 1979 [ESL-TR-79-06].
35. Nicklin D, Balaban DJ: Exercise EKG in asymptomatic normotensive subjects. N Engl J Med 310:852, 1984.
36. Nielson R, Gwosdow AR, Berglund LB, DuBois AB: The effect of temperature and humidity levels in a protective respirator on user acceptability during exercise. Am Ind Hyg Assoc J 48:639–645, 1987.
37. NIOSH Respirator Decision Logic. Cincinnati, National Institute for Occupational Safety and Health, 1987 [DHHS (NIOSH) publ no. 87-108].
38. Raven PB, Davis TO, Shafer CL, Linnebur AC: Maximal stress test performance while wearing a self-contained breathing apparatus. J Occup Med 19:802–806, 1977.
39. Raven PB, Dodson AT, Davis TO: The physiological consequences of wearing industrial respirators: A review. Am Ind Hyg Assoc J 40:517–534, 1979.
40. Raven PB, Jackson AW, Page K, et al: The physiological responses of mild pulmonary impaired subjects while using a "demand" respirator during rest and work. Am Ind Hyg Assoc J 42:247–257, 1981.

41. Ronk R, White MK: Hydrogen sulfide and the probabilities of "inhalation" through a tympanic membrane defect. J Occup Med 27:337–340, 1985.
42. Stemler FW, Craig FN: Effects of respiratory equipment on endurance in hard work. J Appl Physiol 42:28–32, 1977.
43. Turner N, Parker J, Hudnall J: The effect of dry and humid hot air inhalation on expired relative humidity during exercise. Am Ind Hyg Assoc J 53:256–260, 1992.
44. White MK, Hodous T: Reduced work tolerance associated with wearing protective clothing and respirators. Am Ind Hyg Assoc J 48:304–310, 1987.
45. Weiner DA, Ryan TJ, McCabe CH, et al: Exercise stress testing: Correlations among history of angina, ST-segment response and prevalence of coronary-artery disease in the coronary artery surgery study (CASS). N Engl J Med 301:230–235, 1979.

END

5 11 93