61

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Performance Characteristics of Dust Respirators, Bureau of Mines Approved and Non-approved Types

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The performance characteristics of six Bureau of Mines approved and six non-approved respirators were evaluated against seven different dust aerosols. Silica, silicate polishing compound, cement, sulfur, lead, iron and zinc aerosols were used. Approved respirators permitted less particulate penetration of the filters, however some approved respirators failed to meet tests carried out in accordance with the Bureau of Mines approval schedules. Approved respirators were fairly uniform in performance, with few exceptions, but non-approved respirators varied widely in performance. The respirators tested represented a wide range of filter materials and filtering areas.

Introduction

DUST IS an aerosol consisting of solid particles suspended in air which are generated and dispersed into air by mechanical means such as the disintegration processes of *crushing, grinding, abrading, drilling,* and blasting. Dust is the respiratory hazard most frequently encountered in industry. Although the best procedures to prevent inhalation of harmful dusts by personnel are the removal of the particulates at their source of generation or the reduction of the particulate concentration to levels sufficiently low so as not to cause bodily harm, there are situations where, for one reason or another, these procedures are inapplicable, impractical, impossible, or not adequately effective. In such situations, personal respiratory protective devices are utilized to protect personnel. The *dust respirator,* a device which covers the nose and mouth and which contains a porous material that removes dust from inspired air, is the most widely used instrument for protection against dust.

Dust respirators were used in ancient times to protect men against injurious dusts encountered in industrial occupations. The earliest record of a dust respirator dates from Roman times. Pliny the Elder, a Roman author who lived from 23 to 79 A.D., refers in his "Natural History" to the use of loose bladders to cover the faces of miners and refiners of lead oxide to prevent inhalation of "fatal dust." There are many references in the literature, extending from ancient times to the present, pertaining to the employment of dust respirators to protect miners, meal refiners, quarry workers, stone cutters, grain millers, tool grinders, etc. Although dust respirators were widely used in the nineteenth century, no proper study of these devices was made, and consequently the efficiency of the particulate filtering materials was low, the breathing resistance was usually high, and the fit on the face was poor.

In the United States, the matter of adequate functional characteristics for dust respirators based on scientific and engineering principles was not established until as late as the 1930's. On August 20, 1934, the U. S. Bureau of Mines issued a test and approval schedule pertaining to particulate filtering-type respiratory protective devices including

TABLE I
Description of Dust Respirators

Respirator Type	Respirator Designation	Type of Filter Medium	Effective Filtering Area (cm^2)
Approved, single filter	AS1	Electrostatic felt	48
	AS2	Electrostatic felt	42
	AS3	Nonwoven web of synthetic fibers and asbestos	66
Approved, double filter	AD1	Electrostatic felt	73
	AD2	Soft paper	268
	AD3	Nonwoven web of synthetic fibers and asbestos	73
Nuisance dust	N1	Open-cell elastomeric foam	41
	N2	Thin nonwoven web of cellulosic fibers	137
	N3	Cellulosic fiber batt	40
	N4	Open-cell elastomeric foam	154
	N5	Thin nonwoven web of cellulosic fibers	78
	N6	Nonwoven web of synthetic fibers	36

TABLE II
Characteristics of Dust Particulates

Dust Particulate	Geometric Mean Size (microns)	Standard Geometric Deviation	Specific Gravity
Silica[a]	0.51	1.90	2.65
Lead[b]	0.67	1.94	9.98
Polishing compound[c]	0.33	2.42	2.5
Cement	0.74	1.97	2.3
Sulfur	1.03	2.30	2.07
Iron	1.2	1.96	7.9
Zinc	2.0	2.40	7.14

[a]U. S. Bureau of Mines silica dust particulate.
[b]U. S. Bureau of Mines lead dust particulate (75% litharge, 25% lead).
[c]Chiefly silicates.

dust respirators.[1] This test and approval schedule and its subsequent revisions[2,3] do not require that all dust respirators must be submitted to the Bureau for testing and approval. The Bureau has no regulatory power requiring that all respirators must be tested and approved. Submitting respirators to the Bureau for approval is entirely voluntary on the part of the respirator manufacturers. Approved respirators should ensure users of adequate efficiency of removing airborne contaminants from inspired air, sufficiently low breathing resistance, and an economically feasible period of service. The first dust respirator was approved by the U. S. Bureau of Mines in 1935.

Dust respirators, approved by the U. S. Bureau of Mines and nonapproved, made by a number of different manufacturers are available. These respirators differ widely in design, construction, materials, and functional characteristics. The nonapproved devices, popularly known as *nuisance dust* respirators, generally are recommended for protection against nontoxic dusts. Many industrial hygienists and physicians feel that there is no such thing as a nontoxic dust, since inhaling copious quantities of so-called inert dust par-

TABLE III
Performance Characteristics of Dust Respirators for Silica Dust
Range of Dust Concentration: 56.1–60.3 mg/m³
Range of Dust Load: 164.3–173.7 mg

Respirator Type	Respirator	Dust Penetration (%)	Inhalation Resistance at 85 Lpm Initial (mm H_2O)	Final (mm H_2O)
Approved, single filter	AS1	1.3	17.5	44.9
		2.7	21.3	48.5
	AS2	3.2	21.1	46.3
		2.0	27.2	50.3
	AS3	0.3	24.1	38.1
		0.6	24.4	50.0
Approved, double filter	AD1	0.4	8.4	18.0
		0.1	8.9	18.5
	AD2	0.9	36.3	69.6
		0.3	46.3	84.3
	AD3	1.1	13.0	27.9
		1.2	12.2	23.4
Nuisance dust	N1	20.8	6.1	25.9
		31.1	5.6	19.8
	N2	16.7	1.8	84.9
		16.9	1.8	91.2
	N3	32.9	2.0	6.6
		33.3	2.3	7.1
	N4	5.7	41.2	199.4
		4.0	72.4	241.2
	N5	36.2	2.8	37.3
		29.3	2.5	66.8
	N6	28.1	9.7	22.4
		31.5	9.1	16.5

ticulate, especially for long periods of time, can result in adverse physiological effects.

Although the literature contains information concerning the performance characteristics of dust respirators, much of the information is old, pertains to only one specific respirator, or cites the functional characteristics of dust respirators for only one particular type of dust particle.[4-12] Inasmuch as dust respirators are extensively used in industry, the authors felt it important to investigate and report the performance characteristics of modern, commercially available dust respirators, U. S. Bureau of Mines, approved devices and nonapproved devices, for a wide variety of dusts. This information should be helpful to industrial hygienists and safety engineers in aiding them to select the proper dust respirators for protection of workers.

Respirators

Twelve different dust respirators, each made by a different manufacturer, were evaluated. Six of the respirators were approved by the U. S. Bureau of Mines for use against dusts, and the other six were nonapproved nuisance dust type respirators. The respirators employed in the study differed greatly in style, filtering material, and filtering area. All the respirators were purchased on the open market, so they represent what users obtain when they purchase respirators for protection of workers.

Three of the approved respirators employ single filter elements, while the other three use double filter elements. All the approved respirators utilize relatively inexpensive, replaceable filter elements. The approved respirators contain facepieces composed of rubber, plastic, or metal, and the face-sealing edge of all facepieces is either soft rubber or flexible plastic so as to conform to the facial features of the wearer. The approved devices utilize both inhalation and exhalation valve systems. The respirators are approved by the U. S. Bureau of Mines for protection

TABLE IV

Performance Characteristics of Dust Respirators for Lead Dust
Range of Dust Concentration: 18.6–22.7 mg/m³
Range of Dust Load: 53.5–65.5 mg

Respirator Type	Respirator	Dust Penetration (%)	Inhalation Resistance at 85 Lpm Initial (mm H_2O)	Final (mm H_2O)
Approved, single filter	AS1	0.67	19.6	21.3
		0.57	21.1	21.6
	AS2	0.15	25.6	26.9
		0.38	26.7	25.9
	AS3	0.07	23.9	26.2
		0.02	25.4	26.9
Approved, double filter	AD1	0.05	8.9	9.4
		0.02	8.9	9.4
	AD2	0.05	48.0	50.0
		0.02	50.8	53.9
	AD3	0.23	11.7	12.7
		0.53	10.4	11.7
Nuisance dust	N1	14.1	6.9	7.1
		16.6	6.6	7.4
	N2	21.4	1.8	2.3
		13.9	1.8	2.0
	N3	14.0	2.5	3.3
		17.0	2.5	2.8
	N4	1.8	79.8	107.6
		1.2	116.8	153.7
	N5	20.6	2.8	2.9
		26.5	2.8	4.3
	N6	26.7	7.1	7.6
		19.6	9.6	10.2

of personnel against pneumoconiosis-producing and nuisance dusts (dusts having a TLV not less than 2.4 million particles per cubic foot of air) and dusts not significantly more toxic than lead (dusts having a TLV not less than 0.1 milligram of particulate per cubic meter of air). Some of the respirators are approved under Bureau Schedule 21,[1] while others are approved under Bureau Schedule 21A,[2] or 21B.[3] The Bureau does not require that a respirator be upgraded when a test and approval schedule is revised. Once a respirator is approved by the Bureau under a specific schedule, it can be manufactured and sold as long as it conforms to the requirements of the schedule under which it was tested and approved.

All the nonapproved respirators use single filtering elements. Some of the nonapproved devices employ a facepiece, while others do not but instead utilize the filtering element for sealing against the wearer's face. Only one of the nonapproved respirators has both an inhalation and exhalation valve system, two of these respirators contain an exhalation valve system, and the other three respirators have neither an inhalation nor an exhalation valve system. The absence of an exhalation valve system in a respirator means that the wearer must exhale through the filtering element. As the filtering element continues to retain particulate, its resistance to breathing increases—this can be dangerous, inasmuch as it can cause fatigue, since exhalation is not a muscular effort but is instead due to a passive muscular relaxation.

The respirators employed in the study are described in Table I. The effective filtering areas reported were obtained from measurements of areas of respirator filtering elements containing dust particulate deposited during evaluation tests.

TABLE V
Performance Characteristics of Dust Respirators for Fine Polishing Compound
Range of Dust Concentration: 55.9–60.2 mg/m³
Range of Dust Load: 161.0–173.0 mg

Respirator Type	Respirator	Dust Penetration (%)	Inhalation Resistance at 85 Lpm Initial (mm H_2O)	Final (mm H_2O)
Approved, single filter	AS1	2.8	20.1	60.7
		2.0	20.1	53.3
	AS2	2.1	27.4	54.6
		2.2	26.9	51.6
	AS3	0.8	23.1	52.5
		1.1	23.1	50.3
Approved, double filter	AD1	0.6	8.9	19.0
		0.2	9.9	21.3
	AD2	4.8	42.7	75.2
		0.6	47.7	91.4
	AD3	1.3	13.7	26.9
		1.1	13.0	25.2
Nuisance dust	N1	32.1	5.6	17.5
		26.1	7.1	21.6
	N2	14.7	2.3	90.4
		15.6	2.0	70.6
	N3	24.1	2.8	13.0
		24.9	3.0	9.7
	N4	6.4	125.7	381.0
		8.8	64.7	203.2
	N5	23.4	3.0	73.4
		48.7	3.3	31.0
	N6	29.1	9.4	16.5
		27.9	9.7	15.2

Dust Particulates

Seven different particulates were used to evaluate the performance characteristics of the dust respirators. Both nonmetallic and metallic particulates were utilized. The dusts varied widely in particle size and specific gravity. Particle size information was obtained by sampling the dust aerosols with membrane filters and then employing standard optical and electron microscopy methods for particle size measurements. The characteristics of the particulates are given in Table II.

Procedures

A chamber having a volume of 18 cubic meters was used to evaluate the performance characteristics of the dust respirators. Filtered air was passed continuously through the chamber, and provision was made to continuously inject and disperse into the atmosphere of the chamber the particulates. Regulating the flow of air through the chamber and precisely controlling the rate of particulate injection resulted in obtaining the desired concentration of airborne dust particulate in the test atmosphere.

The particulate injector employed is known as the U. S. Bureau of Mines dust freed apparatus.[13] This apparatus utilizes a rising vertical glass tube containing the dust particulate connected to an air ejector. The glass tube containing the particulate is pulled up around a fixed glass tube connected to the ejector. The moving tube is raised at a controlled rate and the particulate is picked up by a whirling airstream and is carried through the fixed tube into the ejector.

Particulate-laden air passes from the injector into an air micronizer which breaks up aggregates of particulate and disperses separate and discrete dust particles into the atmosphere of the test chamber. The air micronizer used is a form of fluid energy mill.[14-16] In this device, compressed air is

TABLE VI
Performance Characteristics of Dust Respirators for Cement Dust
Range of Dust Concentration: 56.7–61.6 mg/m³
Range of Dust Load: 163.2–177.2 mg

Respirator Type	Respirator	Dust Penetration (%)	Inhalation Resistance at 85 Lpm Initial (mm H_2O)	Final (mm H_2O)
Approved, single filter	AS1	3.1	18.5	41.9
		2.1	20.3	45.8
	AS2	1.5	27.4	48.3
		1.7	26.4	46.8
	AS3	0.2	24.6	42.2
		0.3	23.1	40.2
Approved, double filter	AD1	0.3	7.6	16.3
		0.3	8.9	18.8
	AD2	1.5	48.5	79.2
		1.9	44.4	75.7
	AD3	2.1	11.4	19.8
		1.8	12.2	20.8
Nuisance dust	N1	24.2	6.9	17.3
		21.1	7.1	18.8
	N2	15.7	2.0	30.2
		14.5	2.3	32.3
	N3	16.9	2.5	6.3
		16.1	2.8	7.1
	N4	5.5	54.6	315.0
		3.9	81.3	377.2
	N5	18.6	3.0	20.1
		22.6	2.8	22.6
	N6	17.2	7.6	13.0
		13.5	9.1	18.3

fed into a small cylindrical-shaped chamber by jets arranged tangentially to the peripheral wall of the cylindrical chamber. This results in a high-velocity swirling airstream at substantially atmospheric pressure inside the cylindrical chamber. Particulate-laden air from the injector also enters the micronizer chamber tangentially where shearing forces break up aggregates of particulates. The swirling air stream exits from the micronizer at a central opening at its axis, and the airstream disperses separate and discrete dust particles into the atmosphere of the test chamber.

Respirators being tested are sealed to special holders located inside the test chamber. Each holder is connected to a high-voltage alternating-current electric precipitator which collects on a glass tube the particles that penetrate the respirator. An electric precipitator also is used to collect samples of dust particulate in the atmosphere in the chamber for the determination of the concentration of dust in the chamber and for the determination of the dust load passed into a respirator during a test. The principle of operation of the alternating-current electric precipitation is well-known.[17] The precipitators employed are modified versions of those designed and used by the U. S. Bureau of Mines in the testing of particulate filtering-type respirators.[13] A box-shaped baffle projecting from the wall of the test chamber which surrounds the respirators being tested is used to ensure a uniform dust concentration at each of the sampling locations.

Air exiting from a precipitator is passed through a bed of activated carbon granules to remove ozone created in the precipitator, then through a rotameter which indicates the airflow rate, next through a needle valve used to control the airflow, and, finally, through an air pump. The test chamber contains four sampling units, and each samp-

TABLE VII
Performance Characteristics of Dust Respirators for Sulfur Dust
Range of Dust Concentration: 55.5–60.8 mg/m³
Range of Dust Load 159.9–175.2 mg

Respirator Type	Respirator	Dust Penetration (%)	Inhalation Resistance at 85 Lpm Initial (mm H_2O)	Final (mm H_2O)
Approved, single filter	AS1	0.4	19.3	35.8
		1.1	20.3	32.0
	AS2	0.6	25.4	37.3
		0.4	25.9	35.1
	AS3	0.2	24.1	30.2
		0.2	24.6	30.5
Approved, double filter	AD1	0.2	8.9	12.4
		0.3	9.4	15.2
	AD2	0.5	49.8	63.3
		0.7	43.2	54.3
	AD3	0.6	12.4	16.5
		0.5	11.9	15.7
Nuisance dust	N1	13.4	7.1	17.5
		13.5	5.6	18.3
	N2	5.5	2.3	23.9
		8.0	2.0	22.1
	N3	9.3	2.8	14.5
		9.1	2.8	15.2
	N4	0.4	67.1	159.8
		1.2	85.0	209.9
	N5	9.2	2.5	13.5
		10.4	2.5	11.9
	N6	2.6	9.4	15.2
		7.1	7.6	9.6

ling unit has its own air pump. A manometer is connected to each respirator holder downstream of the respirator to measure the resistance to airflow being offered by the respirator during the test.

During a test, the test atmosphere is passed into a respirator at a steady airflow rate of 32 liters per minute for a test period of 90 minutes. The dust particles penetrating the respirator are collected by the glass sample tube of the precipitator, and the mass of penetrating particulate is determined either gravimetrically or by chemical analysis, depending on the particulate composition. A precipitator not connected to a respirator is operated similarly and is used to collect samples of dust in the test chamber's atmosphere throughout the 90-minute test period. The manometer connected to the downstream side of the respirator measures the resistance to inhalation offered by the respirator to the continuous airflow of 32 liters per minute through the respirator during the entire test period. In addition, just prior to the test and just after completion of the test, the inhalation resistance offered by the respirator to a steady airflow of 85 liters per minute is measured. These are the test conditions of dust respirator approval tests carried out by the U. S. Bureau of Mines.[1-3]

Each of the dust respirators was tested against silica dust in the manner employed by the U. S. Bureau of Mines for approval testing of dust respirators for use against pneumoconiosis-producing and nuisance dusts (dusts having a TLV not less than 2.4 million particles per cubic foot of air).[1-3] Each of the dust respirators was evaluated against lead dust in the way that the Bureau carries out approval tests of dust respirators for use against dusts not significantly more toxic than lead (dusts having a TLV not less than 0.1 milligram of particulate per cubic meter of air).[1-3] The silica dust tests were carried

TABLE VIII

Performance Characteristics of Dust Respirators for Iron Dust
Range of Dust Concentration: 56.2–62.8 mg/m³
Range of Dust Load: 161.7–181.0 mg

Respirator Type	Respirator	Dust Penetration (%)	Inhalation Resistance at 85 Lpm Initial (mm H_2O)	Inhalation Resistance at 85 Lpm Final (mm H_2O)
Approved, single filter	AS1	0.9	19.8	20.8
		1.2	20.6	24.1
	AS2	0.8	26.9	28.4
		0.5	27.4	29.5
	AS3	0.2	23.9	30.0
		0.3	23.1	25.6
Approved, double filter	AD1	0.6	8.6	10.4
		0.6	8.9	9.6
	AD2	0.6	48.3	57.7
		0.2	41.2	45.9
	AD3	0.7	12.7	15.8
		0.6	14.5	16.3
Nuisance dust	N1	18.8	5.6	7.6
		13.3	6.1	8.6
	N2	10.6	2.3	6.3
		12.2	2.3	5.8
	N3	7.8	2.5	5.1
		16.1	2.3	3.3
	N4	2.5	95.8	204.5
		2.1	99.0	210.8
	N5	11.1	2.8	18.8
		12.8	2.8	9.9
	N6	14.1	8.1	9.4
		15.2	8.4	9.6

21 5%
21A 2.5
Pb 2.15

out so that the concentration of particulate in the atmosphere in the test chamber would be approximately that of the maximum concentration of 60 milligrams of particulate per cubic meter of air prescribed by the Bureau. The lead dust tests were performed so that the concentration of particulate in the test atmosphere in the chamber would be approximately the maximum concentration of 20 milligrams of particulate (analyzed as metallic lead) per cubic meter of air as ordained by the Bureau.

A respirator approved by the Bureau under Schedules 21 and 21A is permitted a silica dust particulate penetration of 3.0 milligrams, while a respirator approved under Schedule 21B is allowed a silica dust particulate penetration of only 1.5 milligrams. A respirator approved by the Bureau under Schedules 21, 21A, and 21B is allowed a lead dust particulate penetration of 0.43 milligram (analyzed as metallic lead). The mentioned Bureau schedules do not permit the inhalation resistance offered by a dust respirator to exceed 50 millimeters of water for a steady airflow rate of 85 liters per minute.

When the dust respirators were tested against the other five dust aerosols, the procedures employed were those prescribed for U. S. Bureau of Mines dust tests. These tests were carried out so that the dust concentrations in the test atmosphere would be approximately 60 milligrams of particulate per cubic meter of air.

Results

Each of the twelve dust respirators was tested twice against each of the seven dust aerosols. The test results are given in tabular form in Tables III through IX.

Figure 1 graphically illustrates how the silica dust particulate penetration of the nonapproved nuisance dust respirators varied as the mass of silica dust particulate passed

TABLE IX
Performance Characteristics of Dust Respirators for Zinc Dust
Range of Dust Concentration: 58.2–60.3 mg/m³
Range of Dust Load: 167.7–173.5 mg

Respirator Type	Respirator	Dust Penetration (%)	Inhalation Resistance at 85 Lpm: Initial (mm H_2O)	Final (mm H_2O)
Approved, single filter	AS1	1.6	20.6	23.1
		1.8	19.8	21.6
	AS2	0.7	26.4	28.5
		0.8	25.4	27.9
	AS3	0.7	24.4	26.7
		0.4	23.4	25.4
Approved, double filter	AD1	0.7	9.4	10.2
		0.8	8.6	9.7
	AD2	4.5	46.8	49.0
		2.9	48.7	56.2
	AD3	0.5	12.4	13.2
		0.8	12.7	14.0
Nuisance dust	N1	10.9	7.1	7.6
		12.3	6.1	6.9
	N2	7.3	2.0	2.8
		5.5	2.5	4.1
	N3	7.2	2.8	3.0
		8.8	2.3	2.8
	N4	1.7	70.3	99.7
		1.4	86.3	120.7
	N5	25.0	3.0	4.8
		21.3	3.3	5.8
	N6	7.0	8.4	9.1
		8.2	9.7	11.2

into the respirators increased. A graphical illustration of this type for the dust respirators approved by the U. S. Bureau of Mines was not made, since these respirators allowed only a very small quantity of silica dust particulate to penetrate.

Figure 2 is a graphical illustration on how the inhalation resistance of the Bureau-approved dust respirators varied as the amount of silica dust particulate passed into said respirators increased. Likewise, Figure 3 graphically shows how the inhalation resistance of the nonapproved nuisance dust respirators changed as the quantity of silica dust passed into these respirators increased.

Discussion

A review of the test results shows that the nonapproved nuisance dust respirators permitted particulate penetrations that are substantially greater than the penetrations of Bureau-approved dust respirators. In fact, the particulate penetrations of Bureau-approved respirators are only very small fractions of those of the nonapproved respirators. As expected, penetrations of respirators by particles of larger size and greater specific gravity are generally, but not always, less than the penetrations by particles of smaller size and lower specific gravity.

The graphical illustration of the variation of particulate penetration of nonapproved nuisance dust respirators with increase in particulate load into the respirators indicates that the percentage of particulate penetration of these respirators often is very great during the first portion of the test period. This can be dangerous, inasmuch as during this period a respirator offers a relatively low resistance to breathing—thus, the wearer of the respirator may tolerate it only during the time that it offers low breathing resistance and permits a substantial particulate penetra-

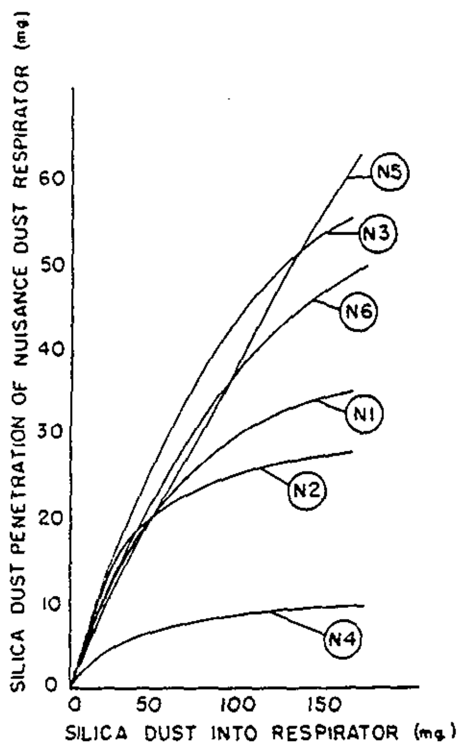

FIGURE 1. Variation of increasing silica dust particulate penetration of *nonapproved nuisance dust* respirators with increasing mass of particulate passed into respirators.

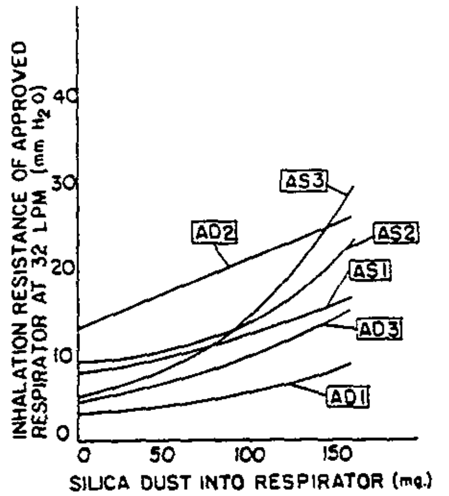

FIGURE 2. Variation of increasing inhalation resistance offered by Bureau-approved dust respirators for 32-lpm airflow with increasing mass of silica dust particulate passed into respirators.

tion, and he discards it when the breathing resistance increases and replaces it with a fresh unit that again allows a substantial portion of the dust to be inhaled.

A review of the silica dust aerosol tests and the lead dust aerosol tests for the dust respirators approved by the U. S. Bureau of Mines indicates that two of these respirators had particulate penetrations greater than that allowed by the older Bureau Schedules 21 and 21A. These test results also show that one of the respirators had final inhalation resistances at the end of both the silica dust tests and the lead dust tests greater than the maximum inhalation resistance permitted by the Bureau.

The test data show that the one nonapproved nuisance dust respirator that allowed much lower dust particulate penetrations than the other respirators of this class had both initial and final inhalation resistances that far exceeded those of the other respirators. In fact, this respirator had final inhalation resistance values that are intolerable.

A review of the test results indicates that, while most types of Bureau-approved respirators are fairly uniform in performance, some types have a significant variation in performance. Also, the test results show that most types of nonapproved nuisance dust respirators vary widely in performance.

Summary

An investigation was carried out to determine the performance characteristics of commercially available dust respirators, both respirators approved by the U. S. Bureau of Mines and nonapproved respirators popularly known as *nuisance* dust respirators. Twelve respirators, six approved types and six nonapproved types, were employed in the study. The performance characteristics of these respirators were evaluated for seven different dust aerosols. Both nonmetallic and metallic particulates were utilized, and the particu-

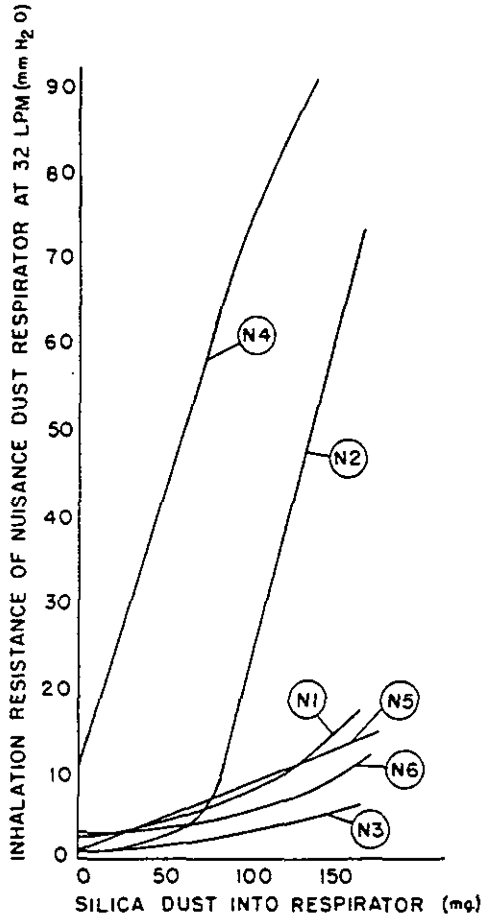

FIGURE 3. Variation of increasing inhalation resistance offered by nonapproved *nuisance dust* respirators for 32-lpm airflow with increasing mass of silica dust particulate passed into respirators.

lates varied widely in both size and specific gravity.

The study shows that the particulate penetrations allowed by the Bureau-approved respirators are only small fractions of the penetrations permitted by the nonapproved respirators. The investigation indicates that, while most types of Bureau-approved dust respirators are fairly uniform in performance, some vary significantly in performance, and most types of nonapproved nuisance dust respirators vary widely in performance.

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