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Current Exposure Guidelines for Particulates Not Otherwise Classified or Regulated: History and Rationale

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Exposure limits and guidelines for particles not otherwise classified or regulated (PNOC/R) evolved from several important studies of pneumoconiosis performed early in the 20th century. These studies indicated that exposure to dust concentrations of less than 50 million particles per cubic foot (mppcf) and with low crystalline silica concentrations did not appear to lead to the development of disabling lung disease. Consequently, dusts containing less than 5 percent crystalline silica were termed "nuisance dusts," and an exposure limit of 50 mppcf was recommended. With the advent of mass sampling technology and the ability to sample directly for respirable dust, exposure limits migrated to total and respirable nuisance dust exposure limits of 15 and 5 mg/m^3, respectively, for dusts containing less than 1 percent crystalline silica. Regulatory exposure limits were established by incorporating these exposure guidelines that were in existence when the enabling legislation was enacted. Changes to regulatory limits have lagged behind threshold limit values adopted by the American Conference of Governmental Industrial Hygienists (ACGIH), which have been updated based on current research. Current ACGIH recommendations for inhalable and respirable dusts are 10 and 3 mg/m^3, respectively. Recent studies of ultrafine particulate and toxicological investigation of the pulmonary overload phenomena from exposure to PNOC/R indicate that exposure to these materials at sufficiently high concentrations can cause irreversible changes to the airways. The term "nuisance dust" was inaccurate, so the terminology of PNOC/R was substituted as a better descriptor for dusts without component-specific exposure limits. Further reductions in exposure limits and guidelines have been proposed for control of occupational exposure to PNOC/R. These proposals are motivated by increasing recognition that clinically significant chronic airways obstruction is caused by occupational dust exposure. HEARL, F.J.: CURRENT EXPOSURE GUIDELINES FOR PARTICULATES NOT OTHERWISE CLASSIFIED OR REGULATED: HISTORY AND RATIONALE. APPL. OCCUP. ENVIRON. HYG. 13(8):608–612; 1998. © 1998 AIH.

The development and evolution of exposure limits and guidelines for particles not otherwise classified or regulated (PNOC/R) was intimately entwined with the development of silica exposure guidelines. In the past decade, the terminology of PNOC/R was introduced to replace the misleading term "nuisance dust" to refer to all dusts other than those with established exposure criteria, and with less than 1 percent crystalline silica content by weight. The new terminology was adopted in recognition of the fact that no dust could be described as a nuisance (i.e., without physiological effects). This article will review the development of the current PNOC/R guidelines and limits from their historical origins in the dusty trades studies of the mid-1920s.

Early Development of an Exposure Limit

In the latter half of the 19th century, scientists began to recognize that disabling and sometimes fatal lung diseases were related to the inhalation of dust particles during work. These lung diseases were often referred to as "miners phthisis" or "consumption." The word "phthisis" derives from Greek, meaning "to waste away." This relationship led some to begin to refer to these diseases as "pneumoconiosis," again from Greek, meaning "dust in the lungs." Toward the end of the century the newly established etiology of tuberculosis, as a disease caused by infectious bacteria, led many to believe that the pneumoconioses were the result of an infectious exposure, and not related to dust. However, studies by British researchers in 1902 and by the U.S. Public Health Service (PHS) in 1911 reconfirmed the connection between dust and disease. Lanza reported that it was possible to injure the lungs by inhaling rock dust, and that the presence of dust-induced disease increased the chance for the individual to contract tuberculosis.(1)

Through the mid-1920s the PHS carried out studies of six dust-exposed cohorts: Portland cement workers,(2) granite workers,(3) coal miners, textile plant workers, silverware manufacturing workers, and municipal dust-exposed workers.(4) In each industry, the workers were given a medical examination including a chest X ray, and their workplace was sampled for dust concentration and the presence of crystalline silica. The companies' absenteeism records were also reviewed. A statistical analysis of mortality and autopsy records was also performed where appropriate.

Dust concentrations were measured using an impinger sampling technique developed by Greenburg and Smith.(5) Impinger samplers drew in dust-laden air through a central column. The air was accelerated through a nozzle and was impinged on a glass surface which was immersed in a collection fluid. Inertial forces separated the particles from the air stream, retaining them in the fluid. After sampling a measured volume of air, particle counting began with the removal of a known portion of the fluid containing the collected dust particles. This measured aliquot was transferred to a counting cell consisting

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TABLE 1. Dusty Trades Study

Industry	Disease	Silica Content (%)	Average Dust Concentration (mppcf)
Cement	Bronchitis, influenza	6–8	26
Granite	Silicosis, tuberculosis	35	9–59
Bituminous coal: rock drillers	Data insufficient, "severe hazard"	54	78
Bituminous coal: loaders and coal cutters	Fibrosis, influenza, pneumonia	1.2	112
Textile	Negative	Unknown	7
Silverware	Negative	1.7	5
Municipal	Negative	Unknown	4

Data are from References 2 through 4.

of a glass microscope slide constructed with a 1-mm deep well to contain the fluid. Particles that settled to the floor of the cell were counted using light field microscopy with a 10-power objective lens.[6] Opaque particles as small as 0.5 μm were counted by trained observers. The total particle count was then computed, noting the ratio between the volume of the withdrawn aliquot and the total volume of the sample. Concentrations reported from impinger samples were usually stated in million particles per cubic foot (mppcf). The results of those studies are summarized in Table 1.

Individual assessments were made in each industry, with the greatest attention given to the granite industry, where both silicosis and tuberculosis problems were the most severe. Further analysis of the data from the granite industry proved to be revealing. When the workers were grouped into four exposure categories, a general dose–response relationship was observed. This relationship is described in Table 2. Based on these data, the investigators concluded that, for workers exposed to granite dust, a "safe limit lies somewhere between the amount of dustiness in groups C and D or between 9 and 20 million particles [per cubic foot]." Russell[7] went on to conclude that a limit of 10 mppcf would appear to be appropriate for these workers where the silica content was measured at 35 percent.

Threshold Limit Values

In the early 1940s, the American Conference of Governmental Industrial Hygienists (ACGIH) adopted a list of threshold limit values (TLVs) for various chemical substances, and included a list of TLVs for mineral dusts.[8] The TLVs for mineral dusts were based largely on the PHS studies from the 1920s and 1930s. The mineral dust TLVs are listed in Table 3. The limit for generic dusts containing less than 5 percent silica, termed "nuisance dust" in the 1946 TLV list, remained at 50 mppcf until 1962. The precision and accuracy of the available silica analytical techniques caused some concern, particularly when the concentration of silica in a dust mixture approached one of the transition values in Table 3. For example, if the silica concentration was near 5 percent, a small difference in the analytical result could change the recommended maximum allowable exposure concentration from 50 to 20 mppcf. Likewise, a small percent change in composition near 50 percent silica could cause a difference between 20 and 5 mppcf, although the real toxic significance between 4 and 5 percent silica or 50 and 51 percent silica would be negligible. To provide for a gradual change in the allowable limit, in 1962 the ACGIH adopted a formula to describe the TLV:

$$\text{TLV} = \frac{250 \text{ mppcf}}{\% \text{ quartz} + 5}$$

This provided a smooth transition over the range of possible silica concentrations in a mixed-dust exposure, and continued to provide protection in the absence of silica for nuisance dust at a level of 50 mppcf.[9]

Following the Johannesburg Pneumoconiosis Conference in 1959, significant effort was devoted to the development of size-selective, mass-based standards.[10] Particle sampling using the impinger was imprecise. Rules for exclusion of large particles were not uniformly applied, nor were all counters and techniques equivalent.[11] Particle counting was variable and depended on the particular laboratory and the training and experience of the person doing the counting.[12] Mass-based standards, using precision balances to preweigh and postweigh filter collection media, were viewed as more accurate and

TABLE 2. Restudy of Granite Workers

Work Group	Average Dust Level (mppcf)	Absentee Rate per 1000 Years	Silicosis or TB
Hand pneumatic tool cutters	40–60	215	Severe disease
Surface machine operators	40–60	215	Severe disease
Plant average	20	105	Some disease
Low dust areas	6*	61	Negative

Data are from Reference 7.
*In the text of the 1941 PHS Report, the data tables report the average dust concentration in the low dust areas (D) at 6 mppcf, as reported in this table. However in the conclusions of the original report, the author states that the dust concentration range for areas C and D was "between 9 and 20 mppcf." In the text, there is further explanation that group D had "an average exposure of 6 million [i.e., mppcf] and a limit of 9 million [i.e., mppcf], where no harmful effect is found." The precise meaning of *limit* quoted from the report is not clear.

TABLE 3. Mineral Dust Exposure Limits: ACGIH 1946 TLVs

Mineral Dust	TLV (mppcf)
Alundum	50
Asbestos	5
Carborundum	50
Portland cement	50
Mica (below 5% free silicon dioxide)	50
Nuisance dust (no free silica)	50
Silica-High, over 50%	5
Silica-Medium, 5–50%	20
Silica-Low, below 5%	50
Slate (below 5% free silicon dioxide)	50
Soapstone (below 5% free silicon dioxide)	50
Talc	20
Total dust (below 5% free silicon dioxide)	50

Data are from Reference 8.

precise than particle counting methods. However, since decades of experience with impinger sampling and particle count-based standards existed, the ACGIH recognized the need for a transition period to gradually move the science to the new mass-based approach. In 1964 the ACGIH again revised its limit for particles not otherwise classified as follows: "A threshold limit of 15 mg/m^3, or 50 mppcf, whichever is less, is recommended for substances in these categories for which no specific threshold limits have been assigned."[13]

During the transactions of the ACGIH in 1970, it was noted that the TLV for inert or nuisance dust had not been lowered for many years, and that much improvement in industrial dust levels had occurred as a result of the original limit.[14] To promote further reduction in industrial dust levels, the ACGIH voted to lower the TLV for dust with no other limit to 10 mg/m^3, or 30 mppcf, whichever was lower. They also added a clarifying definition by which substances should be considered inert or nuisance dusts:

- The architecture of the air spaces remains intact.
- Collagen (scar tissue) is not formed to a significant extent.
- The tissue reaction is potentially reversible.

In addition, the ACGIH also modified its TLV formulas for mixed-dust exposures containing silica to be consistent with these new inert or nuisance dust limits:

$$\text{TLV} = \frac{300 \text{ mppcf}}{\% \text{ quartz} + 10}$$

or

$$\text{TLV}_{\text{respirable}} = \frac{10 \text{ mg/m}^3}{\% \text{ quartz} + 2}$$

By adopting this new respirable dust TLV, the ACGIH established both a respirable PNOC limit of 5 mg/m^3 and a respirable quartz limit of 0.10 mg/m^3, and automatically applied the formula for additive mixed-exposure effects.[15] In 1976 the TLV for nuisance particulate was modified to add a 5 mg/m^3 TLV for respirable nuisance particulate. These limits remained essentially unchanged for the next 10 years.[16]

In 1986 both the 30 mppcf total dust and the 5 mg/m^3 respirable dust TLVs were deleted by the ACGIH. In 1989 the terminology for PNOC was substituted for inert or nuisance particulate to describe those materials containing less than 1 percent crystalline silica and no asbestos, and for which there exists no other independent TLV.[17] During the period between 1986 and 1994 there were no stated limits for PNOC. Only the 10-mg/m^3 total dust TLV was in effect.

In 1994 the ACGIH again modified the PNOC limit to read 10 mg/m^3 inhalable (insoluble) particulate and 3 mg/m^3 respirable insoluble particulate for dusts containing no asbestos and less than 1 percent crystalline silica. The change in the terminology from total dust to inhalable dust has implications for the actual dust concentrations represented by the TLV.[18] The currently supplied inhalable samplers have been shown to collect more than three times as much dust as the 37-mm closed-face cassette samplers that had been previously used to collect total dust samples.[19] This is due to their aerodynamic design, which was developed to better model the collection efficiency of the nose as measured on mannequins in wind tunnel experiments.[20] In those studies, the conventional 37-mm closed-face cassette with its 4-mm diameter inlet was shown to be an inefficient sampler for particles that could reasonably be expected to be inhaled.

Regulatory Limits in the United States

In the United States, the Occupational Safety and Health Administration (OSHA) regulates exposure to PNOR for general industrial operations.[21] The permissible exposure limits (PELs) that were adopted by OSHA in 1970 were incorporated from the ACGIH TLVs that were in effect at the time the Occupational Safety and Health Act was passed. The enforced limits are for total dust at 50 mppcf or 15 mg/m^3, and for respirable dust at 15 mppcf or 5 mg/m^3, although in practice only the mass limits are used today. The OSHA sampling method for total dust remains the 37-mm closed-face cassette sampler. These OSHA limits apply to general industry, as defined by the Code of Federal Regulations.

The mining industries are regulated by the Mine Safety and Health Administration (MSHA) under regulations that apply to surface and underground mines in the coal mining industry and the metal and nonmetal mining industries.[22] For coal mines, all dust found in a coal mine is regulated by definition as "coal mine dust." MSHA enforces a limit of 2.0 mg/m^3 respirable coal mine dust if the crystalline silica concentration is less than 5 percent. For coal mine dust with crystalline silica greater than 5 percent, the respirable dust standard (RDS) for coal mine dust is reduced by the formula

$$\text{RDS} = \frac{10 \text{ mg/m}^3}{\% \text{ quartz}}$$

In metal and nonmetal mines, MSHA incorporated the TLV from the 1973 edition.[23] In that edition, the ACGIH included an appendix table that listed some nuisance dusts in addition to the exposure limits. These are presented in Table 4. Legal interpretations have limited the ability of MSHA to enforce a nuisance dust PEL for metal and nonmetal mines unless the dust appeared in the 1973 appendix list of some nuisance dusts.[24]

TABLE 4. PELs Enforced by MSHA for Metal and Nonmetal Mines (30 mppcf or 10 mg/m³)

Alundum (Al_2O_3)	Kaolin
Calcium carbonate	Limestone
Cellulose (paper fiber)	Magnesite
Portland cement	Marble
Corundum (Al_2O_3)	Pentaerythritol
Emery	Plaster of Paris
Glass, fibrous or dust	Rouge
Glycerin mist	Silicon carbide
Graphite (synthetic)	Starch
Gypsum	Sucrose
Vegetable oil mists (except castor, cashew nut, or similar irritant oils)	Titanium dioxide
Tin oxide	

From: ACGIH TLVs for 1973, Appendix D: "Some Nuisance Particulates."(23)

International Exposure Limits

Other nations have adopted various exposure limits and guidelines for PNOC/R substances. Although these limits are generally stated in terms of a mass–concentration limit (e.g., milligrams/cubic meter), care must be taken when attempting to relate one nation's standards to another. There are several factors that make direct intercomparison difficult or impossible: sampling instruments differ, sampling strategies differ, and sample analysis methods differ. Most total dust samples have been collected using the standard closed-face cassette with its 4-mm inlet. Sampling flow rates for this sampler vary from 1 to 2 L/min. Depending on the sampling flow rate, the collection efficiency for the sampler will vary for different-sized particles. Some countries are now specifying their PNOC/R exposure limits in terms of inhalable or inspirable dust. As with the cassette, the instrument and the conditions under which it is used will determine the effect of the exposure limit on workplace conditions. Sampling strategy can affect the implications of countries' exposure limits. If the strategy involves personal sampling on random workers, a different control outcome will result from a strategy that uses a fixed-point sampler located in an exhaust airway or at a high risk location. Some strategies involve single-shift exposure limits, while others may be more complex, involving the moving average over multiple shifts. Each of these conditions will result in a real difference in protection afforded the workers, even though the value of the exposure limit may be the same. Since crystalline silica is often a factor in how PNOC/R limits are applied, additional variability is introduced when comparing different countries' exposure limits due to the use of the three available analytical methods. With these limitations in mind, some international limits currently in place for PNOC/R materials include:(25)

Australia	10 mg/m³ inspirable dust
China	10 mg/m³ for dust with <10 percent silica
Germany	6 mg/m³ as fine dust
Sweden	10 mg/m³ total dust, 5 mg/m³ respirable dust
UK	10 mg/m³ inhalable dust, 5 mg/m³ respirable dust

Summary and Conclusions

The exposure limits and guidelines for PNOC/R have evolved from PHS studies of the dusty trades that were carried out from the mid-1920s to the late 1930s. For dusts that contain little crystalline silica, the justification for the limits was largely based on reduction of visibility in the workplace and irritant effects to the skin and mucous membranes of the eyes, ears, and nasal passages. The recommended guidelines have changed over the years to incorporate new knowledge about exposures to particulate, to incorporate improved sampling technology, and to serve generally as a technology-forcing motivation to reduce overall exposure to airborne dust. The highlights in the progression of exposure limits and guidelines for PNOC/R are provided in Table 5.

Recent studies of ultrafine particulate and toxicological investigation of the pulmonary overload phenomena from exposure to PNOC/R indicate that exposure to these materials at sufficiently high concentrations can cause irreversible changes to the airways, and consequently present more than an irritation effect.(26) One recent review has recommended an algorithm for setting exposure limits for PNOC/R based on particle density and consideration of the particle size distribution.(27)

Evaluating the effects of exposure to PNOC/R is complex because of the mixed-exposure nature of the materials. For both population studies and laboratory experiments, PNOC/R as generic particles will always present the question of whether or not the observed response is in fact due to the properties and direct action of one or more of the components in the mixture, rather than to the particles without respect to composition. Dealing with this complex mixed-dust problem is an area for further research. Additionally, there is the question of applying various mixture formulas when the PNOC/R mixture also includes a known respiratory hazard, such as

TABLE 5. PNOC/R Guidelines and Limits—Major Changes: 1946 to Present

		1946	1964	1970A	1976	1994–Present
Count (mppcf)	ACGIH	50	50	30	30B	
	OSHA			50	50	50
Total dust (mg/m³)	ACGIH		15	10	10	10C
	OSHA			15	15	15
Respirable dust (mg/m³)	ACGIH				5D	3
	OSHA			5	5	5

AOSHA PELs' effective date was actually May 29, 1971.
BDust particle count TLV deleted in 1986.
CInhalable notation added in 1994.
DRespirable dust limit deleted in 1986; restored in 1994 at 3 mg/m³.

crystalline silica. The use of the former TLV formula for exposure to dusts containing quartz provided for a reduced exposure limit for both when mixed-dust exposures occur. With the present ACGIH recommendation to control exposures to PNOC separately from respirable crystalline silica, it is not clear that the additive-mixture formula will continue to be widely applied by practicing industrial hygienists. Regardless, control of occupational exposure to PNOC/R should be motivated by increasing recognition that clinically significant chronic airways obstruction is caused by occupational dust exposure.[28]

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