

nitrogen, and sulfur. "Hard" coal refers to coal with a higher carbon content (*i.e.*, 90–95%) than "soft" coal (*i.e.*, 65–75%). Coal rank relates to geologic age, indexed by its fixed carbon content, down to 65%, and then by its heating value. Volatile matter varies inversely with the fixed carbon value. The most commonly described coal ranks include lignite (low rank), bituminous coal (medium rank), and anthracite (high rank) (Manahan, 1994).

2. Physical State: Coal Mine Dust

Aerosols are a suspension of solid or liquid particles in air (Mercer, 1973); they may be dusts which are solid particles suspended in the air. Coal dust may be freshly generated or may be re-suspended from surfaces on which it is deposited in mines. As discussed below, coal mine dust may be inhaled by miners, depending upon the particle size.

Coal mine dust is a heterogeneous mixture, signifying that all coal particles do not have the same chemical composition. The particles are influenced by the type, grade, and rank of coal from which they were generated (Manahan, 1994). Irrespective of differences in coal characteristics, these dusts are water-insoluble, which is important biologically and physiologically. Unlike soluble dusts which may readily pass into the respiratory system and be cleared via the circulatory system, insoluble dusts may remain in the lungs for prolonged periods of time. Thus, a variety of cellular responses may result that could eventually lead to lung disease.

3. Biological Respirable Coal Mine Dust

The principal route of occupational exposure to respirable coal mine dust occurs via inhalation. As a miner breathes, coal mine dust enters the nose and/or mouth and may pass into the mid airways (*e.g.*, bronchi, terminal bronchioles) and lower airways (*e.g.*, respiratory bronchioles, alveolar ducts).

Coal mine dust has a size distribution that is estimated to range between 1 and 100 micrometers (μm) ($1 \mu\text{m} = 10^{-6} \text{ m}$) (Silverman, *et al.*, 1971). The size of coal particles is critical in determining the level of the respiratory tract at which deposition and retention occur (American Conference of Governmental Industrial Hygienists, 1999; American Industrial Hygiene Association, 1997).

Particles that are greater than $10 \mu\text{m}$ are largely filtered in the nasal passages. However, it has long been known that some particles greater than $10 \mu\text{m}$ in size, can be inhaled, and that some of these particles can reach the alveoli of the lungs (Lippman and Albert, 1969).

According to the British National Coal Board, "particles as large as 20 microns (*i.e.*, micrometers (μm)) mean diameter may be deposited, although most 'lung dust' lies in the range below 10 microns diameters" (Goddard, *et al.*, 1973). Particles less than $10 \mu\text{m}$ in size easily move throughout the respiratory tract. As particle size decreases from 10 to $5 \mu\text{m}$, however, there is greater penetration into the mid and lower regions of the lung. Particles that are approximately $1\text{--}2 \mu\text{m}$ are the most likely to be deposited in the lung (American Conference of Governmental Industrial Hygienists, 1999; Mercer, 1973). During mouth breathing, there may be a slight upward shift in the particle deposition curve such that $2\text{--}3 \mu\text{m}$ -sized particles are the most likely to be deposited in the respiratory tract (Heyder, *et al.*, 1986). Irrespective of nasal or mouth breathing, the potential respiratory tract penetration of particles less than $10 \mu\text{m}$ in size is important because particles in the respirable size range deposit in the deep lung where clearance is much slower.

For the purposes of this rule, "respirable dust" is defined as dust collected with a sampling device approved by the Secretary of Labor and the Secretary of the Department of Health and Human Services (DHHS) in accordance with 30 CFR Part 74 (Coal Mine Dust Personal Sampler Units). In practice, the coal mine dust personal sampler unit has been used in the U.S. The particles collected with an approved sampler approximate that portion of the dust which may be deposited in the lung (West, 1990; 1992). It does not, however, indicate pulmonary retention (*i.e.*, those particles remaining in the lung). For those particles that are deposited in the lung, clearance mechanisms normally operate to assist in their removal. For example, within the thoracic (tracheal-bronchial) region of the lung, cilia (*i.e.*, hairlike projections) line the airways and are covered by a thin layer of mucus. They assist in particle clearance by beating rhythmically to project particles toward the throat where they may be swallowed, coughed, sneezed, or expectorated. This rhythmic beating action is effective in removing particles fairly quickly (*i.e.*, hours or days). Within the alveolar region of the lung, particles may be engulfed by pulmonary macrophages. These large "wandering cells" may remove particles via the blood or lymphatics. This process, unlike the movement of the cilia is much slower (*i.e.*, months or years). Thus, some particles, particularly those that are insoluble, may remain in the

alveolar region for long periods of time, despite the fact that pulmonary clearance is not impaired. It is the pulmonary retention of coal mine dust which may be the impetus for respiratory disease.

It is also important to note that silica may be present in the coal seam, within dirt bands in the coal seam, and in rock above and below coal seams. Of the silica found in coal mines, quartz is the form which is found. Thus, quartz may become airborne during coal removal operations (Manahan, 1994). Miners may inhale dust that is a mixture of quartz and coal. MSHA is concerned with the inhalation of quartz since it may be deposited in the lungs of miners and produce silicosis. This is a restrictive lung disease which is characterized by a stiffening of the lungs (West, 1990; 1992). Silicosis has been seen in coal miners (*e.g.*, surface miners, drillers, roofbolters) (Balaan, *et al.*, 1993). Silicosis may develop acutely (*i.e.*, 6 months to 2 years) following intense exposure to high levels of respirable crystalline quartz. Silicosis has also been observed in coal miners following chronic exposure (*i.e.*, 15 years or more), but may be accelerated (*i.e.*, 7–10 years) in some cases (Balaan, *et al.*, 1993). Silicosis is irreversible and may lead to other illnesses and premature mortality. People with silicosis have increased risk of pulmonary tuberculosis infection and an increased risk of lung cancer (Althouse, *et al.*, 1995; International Agency for Research on Cancer, 1997). MSHA's current standard of 2.0 mg/m^3 for respirable coal dust requires that quartz levels in the respirable coal mine dust be 5% or lower. Otherwise, the 2.0 mg/m^3 respirable coal dust exposure limit does not apply and must be adjusted downward for percentage of quartz. If respirable coal mine dust contains more than 5% quartz, then the following formula is applied (30 CFR 70.101; 30 CFR 71.101).

Respirable dust standard (mg/m^3) = $\{(10)/(\% \text{ Quartz})\}$

The intent of this formula, as prescribed by the Secretary of Health, Education, and Welfare in 1971, whenever the respirable coal mine dust in the mine atmosphere of the active workings contains more than five percent quartz, is to maintain miner exposures to quartz below 0.1 mg/m^3 ($100 \mu\text{g/m}^3$).¹⁵

¹⁵ The applicable dust standard for intake air in § 70.100(b) and for miners who have exercised rights under Part 90 regulations in § 90.100 is 1.0 mg/m^3 . Those standards are also lowered if the quartz content of the respirable coal mine dust