

# Pneumoconiosis

Jud W Gurney MD  
University of Nebraska

Welcome, in this presentation, I will review the dust disorders asbestosis and silicosis.

## Overview

Fate of dust in the lung

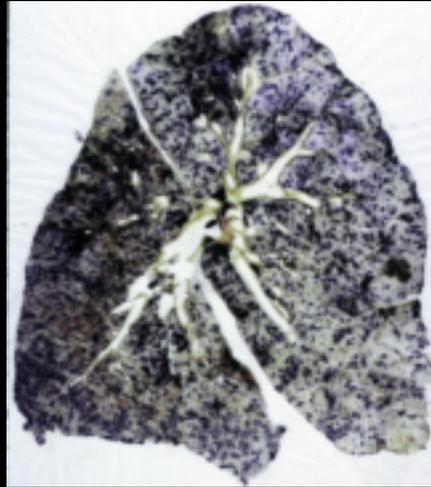
Inorganic lung disease

Organic lung disease

I will begin with an overview of the fate of dust particles within the lung, that is, where is dust deposited and how the lung clears and responds to dust particles. Then, I will discuss the inorganic dust diseases: silicosis and asbestosis.

...and the dust, which is stored and beaten up by digging penetrates into the windpipe and lungs and produces difficulty in breathing

Agricola 1526



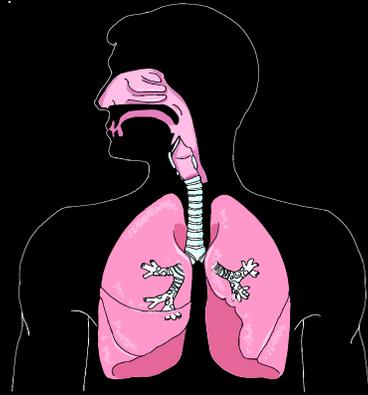
Dust diseases have been known since antiquity. The two essential form of work, farming and hunting, expose workers to the harmful effects of dust from stored grain and dust from fashioning flint tools and weapons. All lungs accumulate dust, like the rings of a tree, the traces of a man's trade and habits are inscribed upon the lung.



1000 particles/ml  
100 - 150 gr/yr inhaled  
1 - 10 g deposited  
0.5 g retained  
20 gr over 40 years  
(40 gr Normal dry lung wt)

What's a dusty environment. Let's consider a coal mine which contains approximately 800-1000 particles/ml, will inhale between 100 to 150 grams of dust yearly. Of the dust inhaled, about 1 to 10 grams is deposited in the alveoli, but only about 0.5 gr is permanently retained. Over 40 years of working, this amounts to 20 grams, half as much as the weight of the normal dried lungs.

## Respiratory compartments



Nasopharynx  
Tracheobronchial  
Pulmonary

Even though there is no physical filter between our lungs and the environment, particles have difficulty reaching the lung. Protection is primarily afforded by the physics of air flow in the complex anatomy of the respiratory system, which can be arbitrarily broken down into 3 compartments the nasopharyngeal, tracheobronchial conducting airways and the pulmonary region composed of the respiratory bronchioles and alveolar sacs.

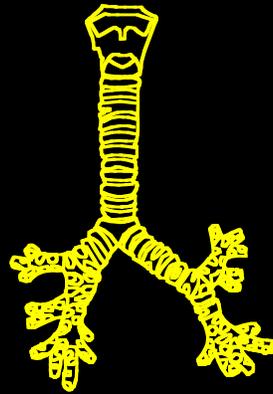
## Nasopharyngeal



Flow: high  
Dynamics: turbulence  
Fate: inertial impaction  
Filtered: > 5 microns

A large portion of the protection occurs in the nasopharynx. Air flow is directed through two 90 degree turns through the baffling of the turbinates such that most particles >5 microns in size are removed.

## Tracheobronchial



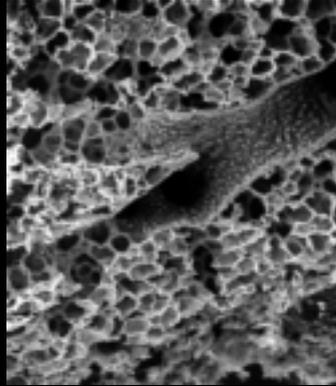
Flow: high  
Dynamics

Turbulence central  
Laminar peripheral

Fate: inertial impaction  
Filtered: > 5 microns

Inertial impaction continues in the tracheobronchial airways as particles are directed to the airway wall or driven into bifurcation points. This effectively removes particles more than 5 microns in diameter.

## Pulmonary



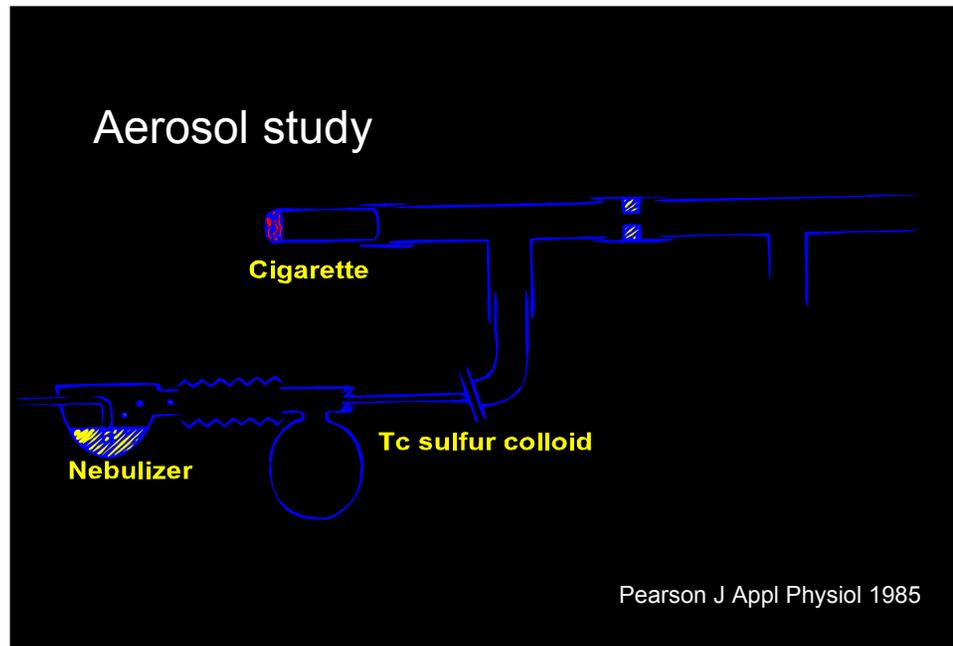
Flow: slow

Dynamics: diffusion

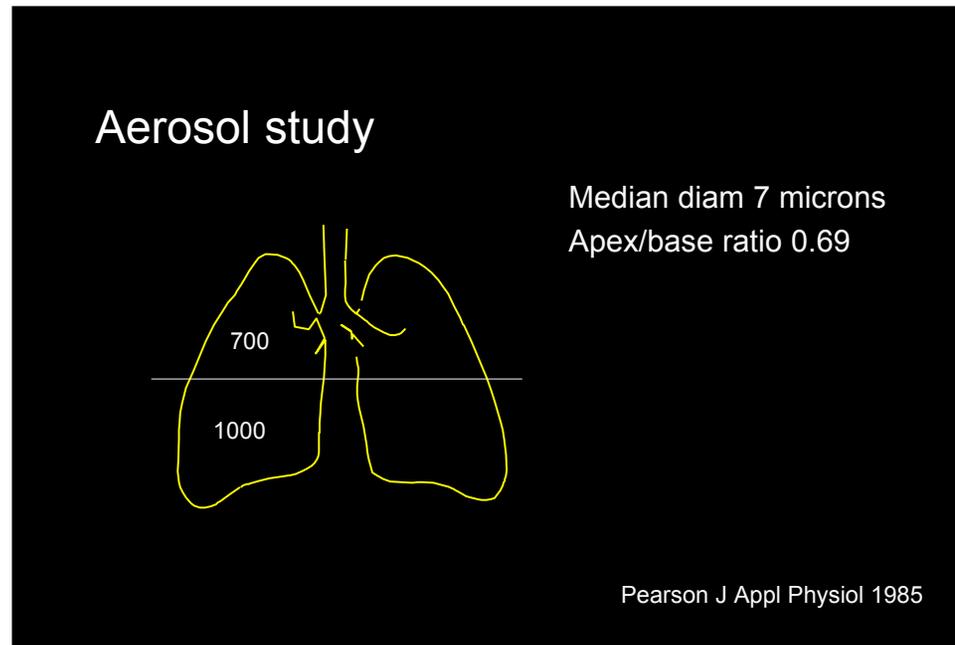
Fate: gravitational settling

Filtered: 1- 3 microns

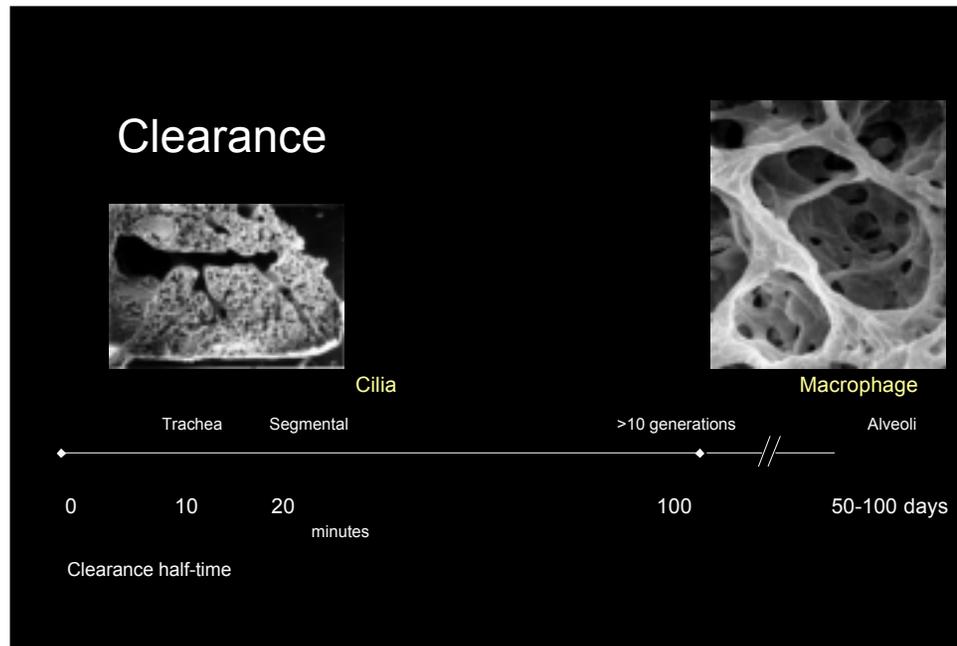
After running the gauntlet of the airways, the remaining particles reach the respiratory bronchioles and the alveoli. The respiratory unit has a large volume, 40x that of the airways and airflow nearly stops, diffusion becomes the main driving force. Particles now can settle out of the airways, particularly in the respiratory bronchioles. Generally, only particles 1 - 3 microns in diameter can make it this far.



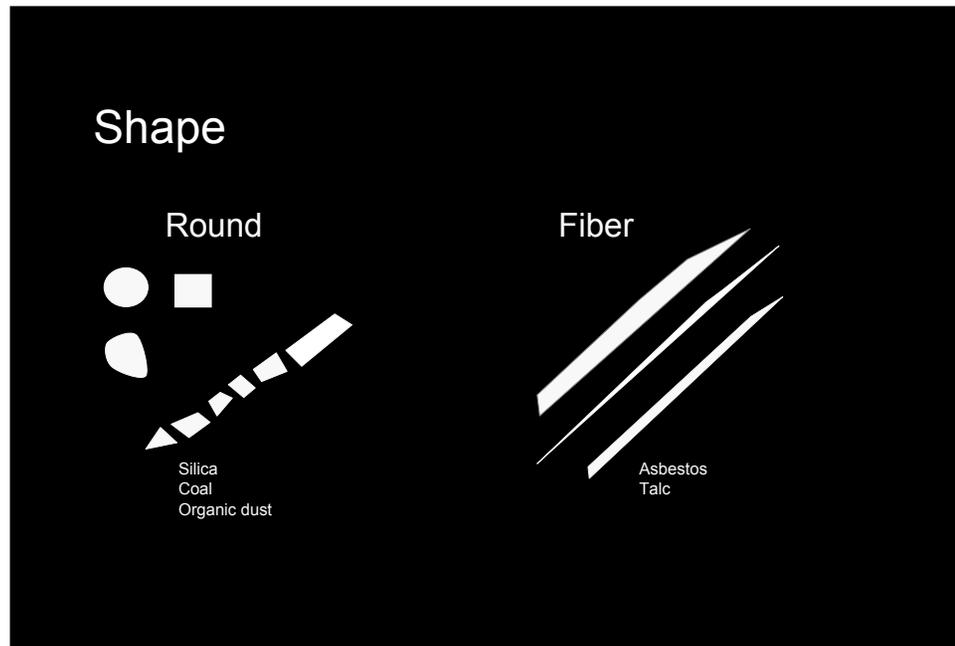
Studying particulate deposition in the lungs is difficult. Animal models have different respiratory dynamics than the human lung. Computer modeling is difficult due to flow dynamics in irregular branching tubes. Human studies are only feasible with radionuclide labeled particles. This particular setup can be used to study the dynamics of particles during smoking.



What we know, from studies such as this is that particle deposition follows the known distribution of pulmonary ventilation, that is, because of gravity, most particles will deposit in the lower lobes. Thus for every 1000 particles deposited in the lower lung zones, 700 are deposited in the upper lung zones.

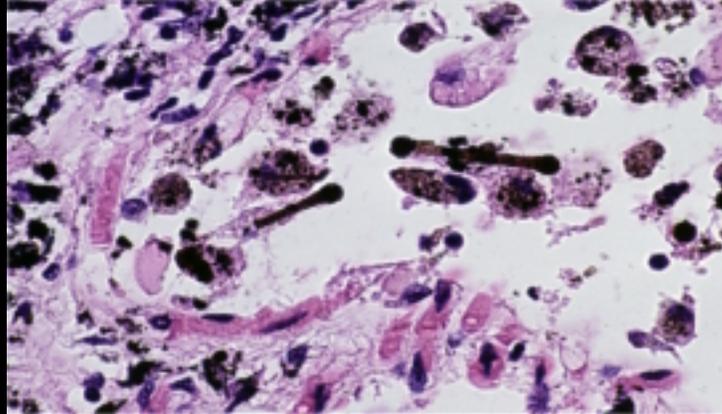


Deposition is not the whole story. Particles once deposited are cleared. From the nasopharynx down to terminal bronchiole, cilia are remarkable efficient in removing particulate material such that at the level of the terminal bronchiole, the smallest ciliated airway in the lung, the clearance half-time is on the order of 100 minutes. If it takes 4 1/2 half-times to remove nearly all particles then the conducting airways are cleared within 8 hours. However, at the level of the respiratory bronchiole and alveoli, there are no cilia. Particles are absorbed into the lung or engulfed by macrophages which make their way into the lung lymphatics. This removal is much slower, roughly 50 days, thus taking nearly a year to remove the particulate burden.



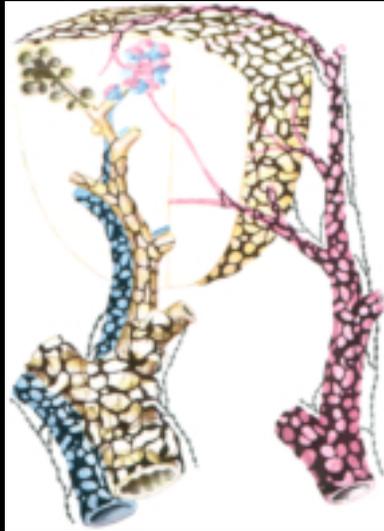
Particles come in nearly all sizes and shapes, most are rounded, some are fibrous. A fiber is defined as a particle with an aspect ratio greater than 3 (ratio of long and short axis). The shape of a particle, irrespective of its chemical properties, plays an important role in clearance. Note that when fibers fragment, these particles may now fit into the round categories.

## Asbestos body



Although the asbestos fiber, commonly >40 microns in length, would seem much too large to reach the respiratory bronchioles, the aerodynamic properties of the long thin fiber acts like a particle less than 5 microns in diameter. However, in contrast to small particles, which can be engulfed and removed by macrophages, the long asbestos fiber is much too long to be removed in this manner. In fact, the asbestos body is nothing more than the cellular reaction from a number of now dead macrophages which tried to ingest and remove the asbestos fiber.

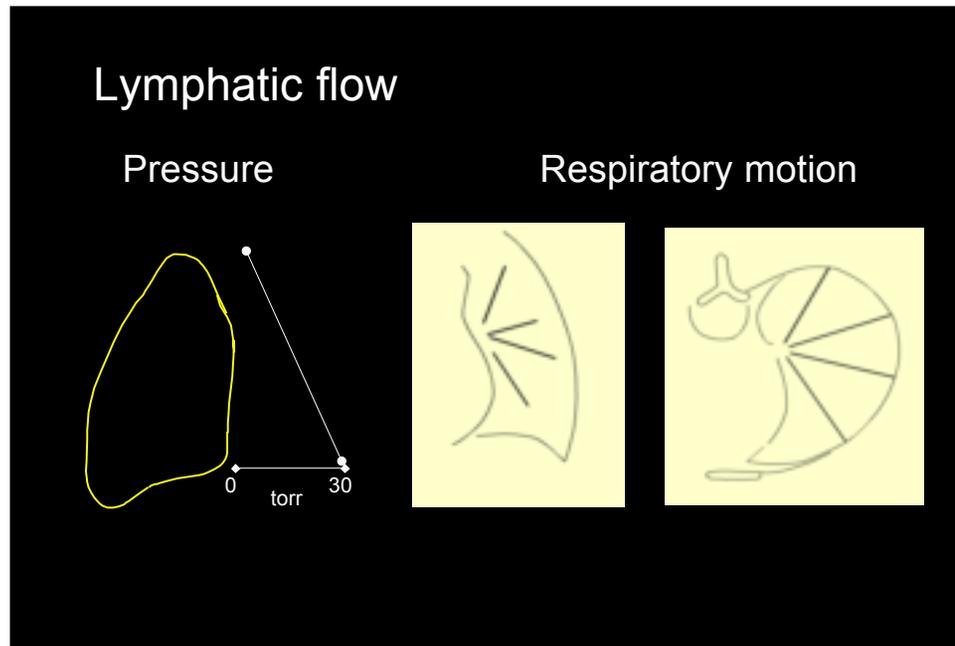
## Lung lymphatics



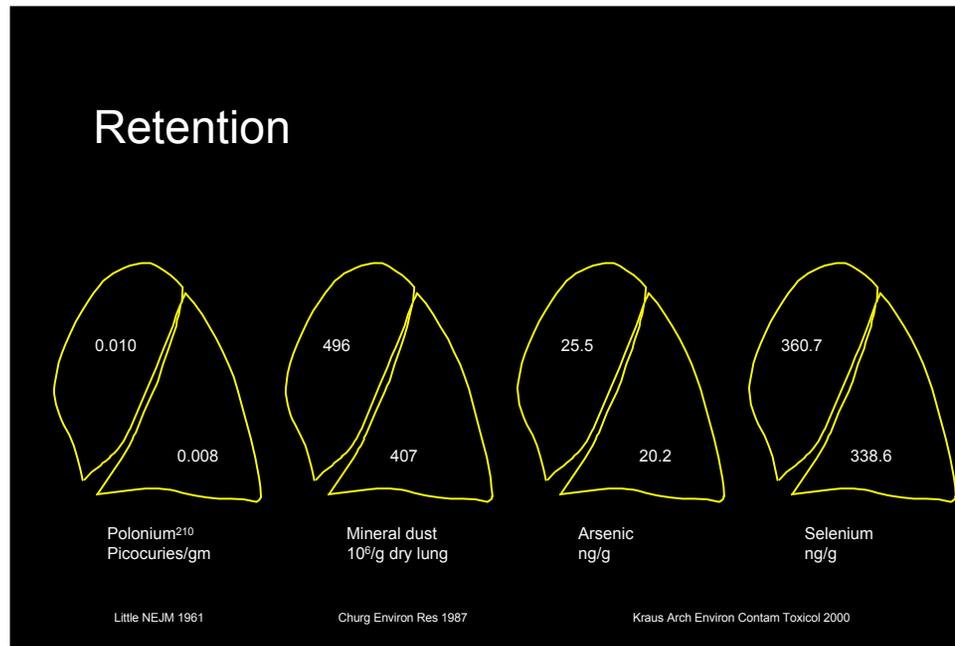
Flow:  
Arterial pressure  
Respiratory motion

Nagaishi Functional anatomy and histology of the lung 1972

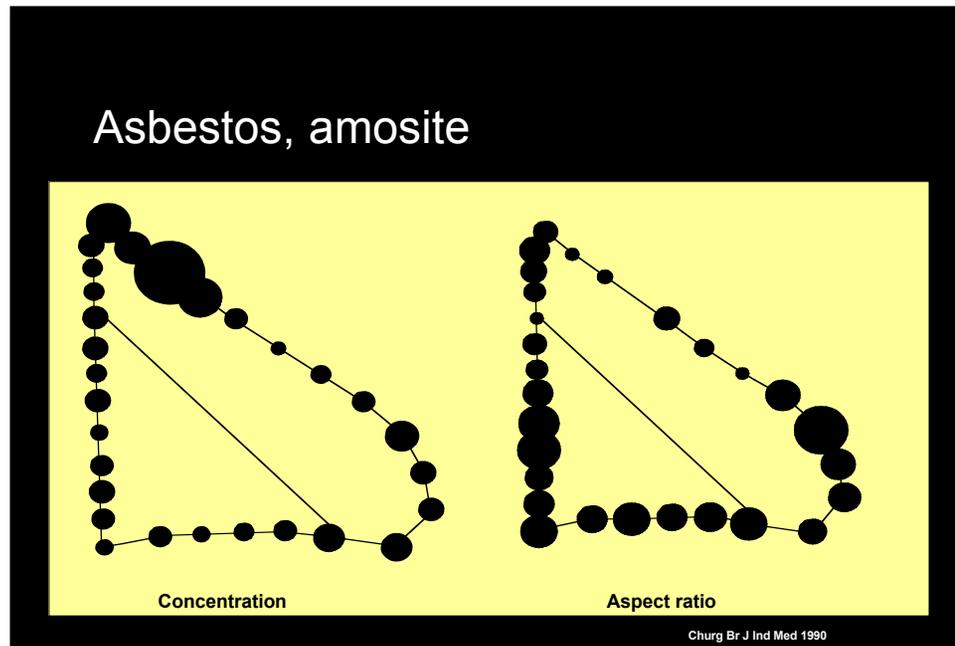
Note that the respiratory bronchiole and alveolar unit are devoid of lymphatics. The lung lymphatics are composed of two systems, one along the bronchovascular bundle and the second peripheral system along the pulmonary veins. What happens to particles that reach the respiratory bronchioles? Well they can be absorbed or engulfed by macrophages. Some are trapped forever. Those particles which can be engulfed by macrophages are removed through the lymphatics (or migrate to the terminal bronchiole and escape via the cilia). As we've seen, removal of particles is slow. Lymphatic flow is, in part, determined by arterial pressure and respiratory motion, which aids lymphatic flow.



Arterial pressure is nonuniform, the low pressure pulmonary artery system is linearly affected by gravity. Normal pulmonary pressure is just sufficient to perfuse the apex of the lung, thus the driving pressure for lymphatic flow will diminish towards the lung apex. In addition, passive respiratory motion is nonuniform, the lung bases and the anterolateral portion of the lung undergoes greater degree of respiratory expansion than the apices and dorsal aspect of the lung.

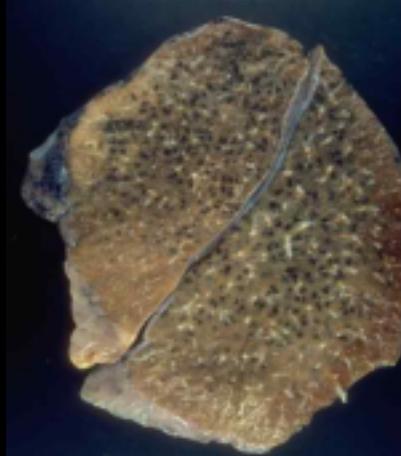


Well, that's the theory of particle clearance. How does that work out in practice. The chronic retention of particulate material can be determined by autopsy examination of different elements. Even though the analyses involve different methods, the results are remarkably similar. Particles tend to accumulate over time in the upper lobes, approximately 1.25 times that of the lower lobes.



I already suggested that fibers, because of their size may be handled differently. Churg studied the distribution of amosite in 9 lungs, the circles proportionately representing the quantity studied. Similar to the rounded dusts, the concentration of asbestos particles is greatest in the upper lobes. However, the concentration of fibers, as measured by the aspect ratio, is greatest in the inferior aspect of the lung, again reflecting the inability of the lung to remove the long thin fiber. Length it turns out, is one physical aspect which determines the pathogenicity of the asbestos fiber.

True distribution?



Because gravitational physiology is important in the distribution of dust particles in the lung, then the anatomical lobar analysis used in these investigations is the incorrect method. For example, in this sagittal section of the lung, the lower portion of the upper lobes and the upper portion of the lower lobe occupy the same gravitational plane. Thus, an analysis based on anatomic boundaries will blur the true distribution of particulate material in the lung. The correct analysis would bread-loaf the lung, horizontal planes perpendicular to the gravitational axis. In this lung, mineral pigmentation gradually diminished toward the lung base. Note the degree of pigmentation in the superior segment of the lower lobe is the same as the upper lobe.

## Fate of particles

Deposit respiratory bronchioles

Rounded particles removed by lymphatics

Deposition and clearance inhomogenous



Let me try to summarize the fate of particles within the lung. Small particles may make it to the respiratory bronchioles. In many diseases the pathology is centered on the respiratory bronchioles. This includes asbestosis, coal workers pneumoconiosis, Langerhans granulomatosis and centriacinar emphysema. Rounded particles tend to be removed by lymphatics so that pathologic findings follow a bronchovascular distribution, a centriacinar distribution along the terminal bronchiole and a subpleural distribution along the chest wall and fissures. Finally, both deposition and clearance are determined by pulmonary physiology, round nodules tend to concentrate in the dorsal aspect of the upper lung zones and fibers in the periphery of the lower lung zones. With this basis in the fate of particles, let's now turn our attention to the inorganic dusts - first the fibrous dust asbestos and then the rounded dusts silica and coal.

## Asbestos

Pleural effusion

Pleural plaques

Interstitial lung disease

Mesothelioma

Lung cancer

Over 30 million tons of asbestos was used in industry over the last century. Fire-proof and of high tensile strength, asbestos a valuable product in construction. Asbestos is a term used to encompass a range of fibrous silicates, categorized as serpentine (chrysotile 90%) and the straight amphibole (crocidolite). Unfortunately, all asbestos fibers are capable of producing a wide variety of thoracic manifestations, these manifestations form a continuum from effusion to interstitial lung disease, Cellular reactions to asbestos fibers can be demonstrated within hours in laboratory conditions, however clinical disease takes decades to develop.

## Asbestos effusion

10 year latency  
2/3'rds asymptomatic  
Small, uni or bilateral  
Spont resolves over 6 months



The first manifestation of exposure to asbestos is the pleural effusion, occurring within 10 years of exposure. Most are asymptomatic with exudative often bloody effusions. Most spontaneously resolve within a few months though some may persist for years. Why effusions resolve is a complete medical mystery.

## Pleural plaques

20 yr latency

Bilateral L > R

None

20% asbestosis

90% mesothelioma



The next pathologic findings is the pleural plaque, seen 10 years later. The pleural plaques tend to develop along the postero- and antero-lateral chest wall and the central tendon of the diaphragm. Plaques are often holly leafed shaped along the chest wall or butte shaped when seen in profile. Plaques are usually bilateral but when unilateral, plaques are more often left sided and when bilateral, plaques tend to be more severe on the left as is seen in this example. Plaques are not always seen in the later manifestations of asbestos disease, 20% of those with asbestosis lack plaques and the majority of patients with mesothelioma lack plaques..

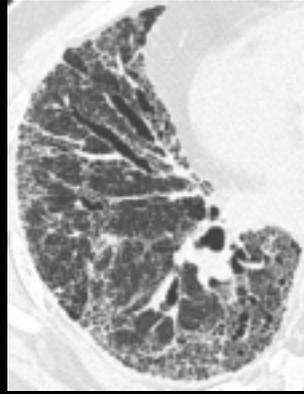
## Asbestosis

30 yr latency  
Clinical Diagnosis (4/5)  
  exposure hx  
  DOE  
  insp crackles  
  abn cxr  
  restrictive PFT's  
Usually Not biopsied



Asbestosis is dose related and seen in those with continued prolonged exposure to asbestos fibers. Typical radiographic findings are basilar peripheral irregular shaped reticular opacities (ILO s,t,u). Fibrosis is associated pathologically with >1 million fibers/gm lung. Diagnosis is generally a combination of clinical and radiograph findings. Rarely are the individuals biopsied, primarily for legal reasons. Generally, there is no benefit to the patient to risk biopsy.

## HRCT



Interlobular short lines  
Long parenchymal bands  
Coarse honeycombing  
Ground glass opacities  
Centriacinar nodules  
Subpleural curvilinear  
shadow

HRCT is more sensitive than the chest radiograph for the detection and characterization of asbestosis. Signs include.....  
Differential diagnosis includes IPF, NSIP, drug reactions, chronic hypersensitivity pneumonitis, and lymphangitic tumor.

## Asbestosis vs IPF

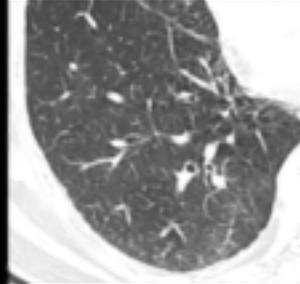
### Favors asbestosis

- Pleural plaques
- Subpleural branching opacities
- Subpleural curvilinear lines
- Parenchymal bands
- Homogeneous subpleural opacities

Akira AJR 2003

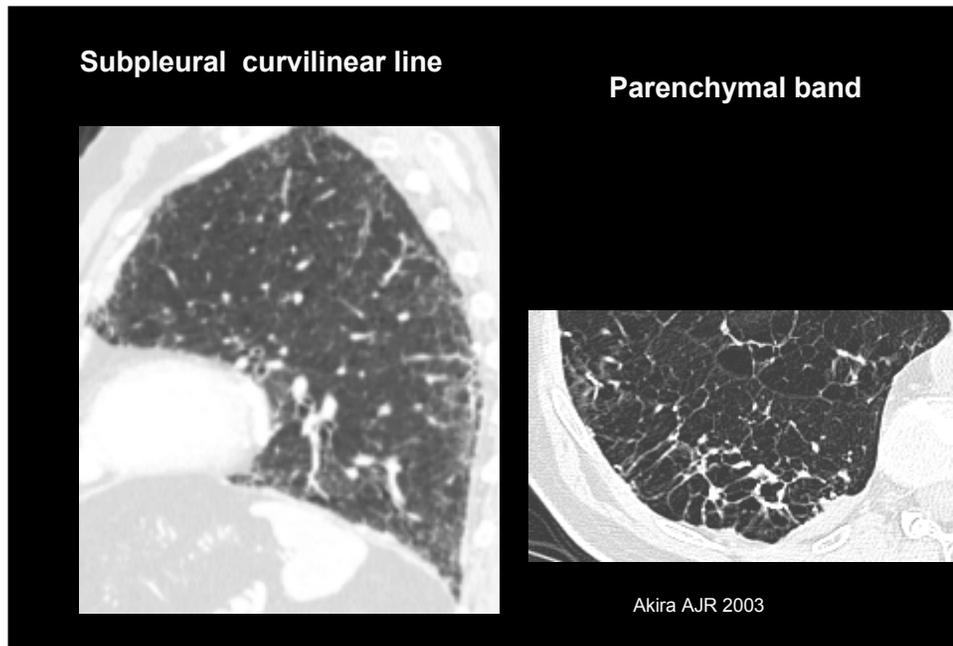
For legal reasons, the differentiation between IPF and asbestosis is of some importance. Pleural plaques are seen in the majority of those with asbestosis. Of course, those with pre-existing asbestos exposure are not immune from developing IPF or the collagen vascular diseases. In addition, 20% of patients with asbestosis won't have pleural plaques. Other helpful clues include.....

## Subpleural branching opacities



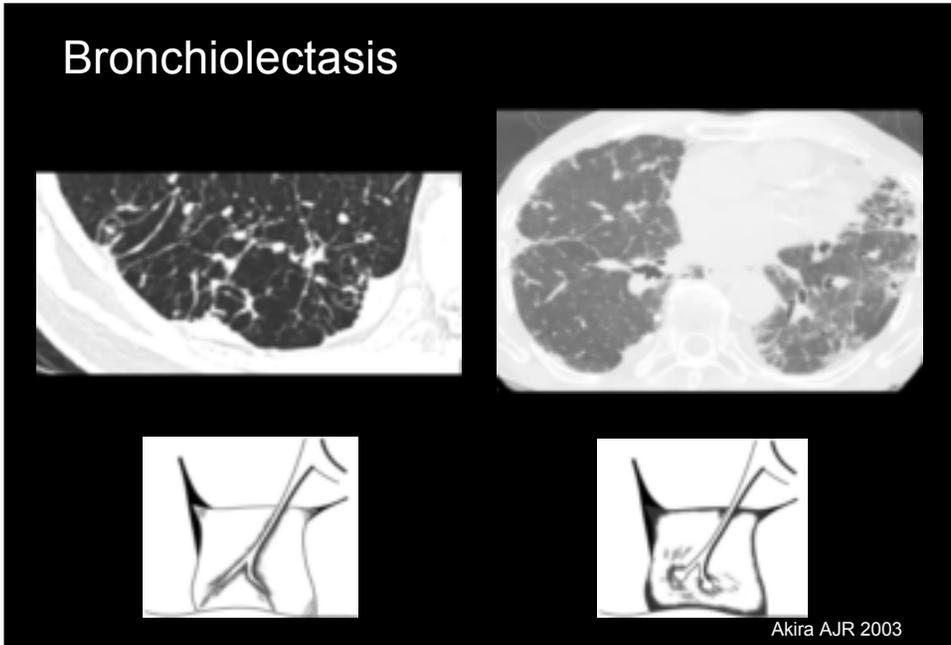
Akira AJR 2003

Early fibrosis from asbestosis is centered on the respiratory bronchioles. Normally the respiratory bronchioles are below the limits of resolution of CT, however, with fibrosis, the wall becomes thickened, to the point where it is now visible.



Both the subpleural curvilinear line, seen in this sagittal reconstruction of the lung and parenchymal bands are much more common in asbestosis than IPF. Parenchymal bands, however, are seen almost exclusively in those with pleural plaques, making this finding alone less useful; and the subpleural line is a very nonspecific finding in and of itself as it may be seen in normal individuals and in those with a wide variety of interstitial lung diseases that narrow the small airways.

## Bronchiolectasis



Finally, small peripheral wedge-or hump-shaped homogeneous opacities are more common in asbestosis as compared to the same opacities in IPF where the distal airways are dilated. Again this probably reflects differences in pathology where in asbestosis, fibrosis is centered around the small airways, obliterating their lumen in contrast to IPF where more peripheral fibrosis results in traction bronchiolectasis of the small airways.

## Lung cancer



Reverse upper-lower

Normal

2.5:1

Asbestosis

2:3 to 7:53

Lung Cancer screening?

Asbestos is an independent risk factor for the development of lung carcinoma, equivalent to that of a smoker. If the exposed individual also smokes the risk is multiplicative. Nearly 1/3 of those smokers with asbestosis die of lung cancer. In those with asbestosis, the cancer is more likely to arise in the lower lobes in contrast to general smokers. Because of the high incidence of lung cancer this raises the question of whether asbestos exposed workers with pleural plaques should be screened for lung cancer.

## Mesothelioma



30-45 yr latency  
Long fibers  
Poor prognosis

Mesothelioma is a rare pleural malignancy seen with asbestos exposure. Curiously, in contrast to this example, the majority have no plaques. Long thin fibers are more likely to induce mesothelioma, thus crocidolite is more neoplastic than chrysotile. The hemithorax is usually small, pleural effusion is nearly universal. Prognosis is poor, 12 month median survival.

## Silicosis & CWP

- Simple
- Complex (PMF)
- Silicoproteinosis
- Caplan's

Now let's examine the rounded dusts, using silica as our prototype. Silica is the most common element in the earth crust. All mining operations, whether iron or coal, contain silica, Sandblasting, foundry work are common industries for silicosis. Again, there are several different thoracic manifestations from silica exposure and we will look at each of these briefly.

## Simple silicosis

10-20 yr latency

Small nodules

Egg-shell lymph nodes



Generally simple silicosis is asymptomatic and is seen in those workers exposed to relatively low levels of dust. However, simple silicosis is a progressive disease even after removal from the dusty environment. Differential diagnosis for an upper lobe nodular pattern includes the granulomatous diseases, (tuberculosis, sarcoid), Langerhan's cell granulomatosis, and Farmer's lung.

## HRCT

Nodules 1-3 mm  
bronchovascular  
centriacinar  
subpleural

Dorsal

R > L



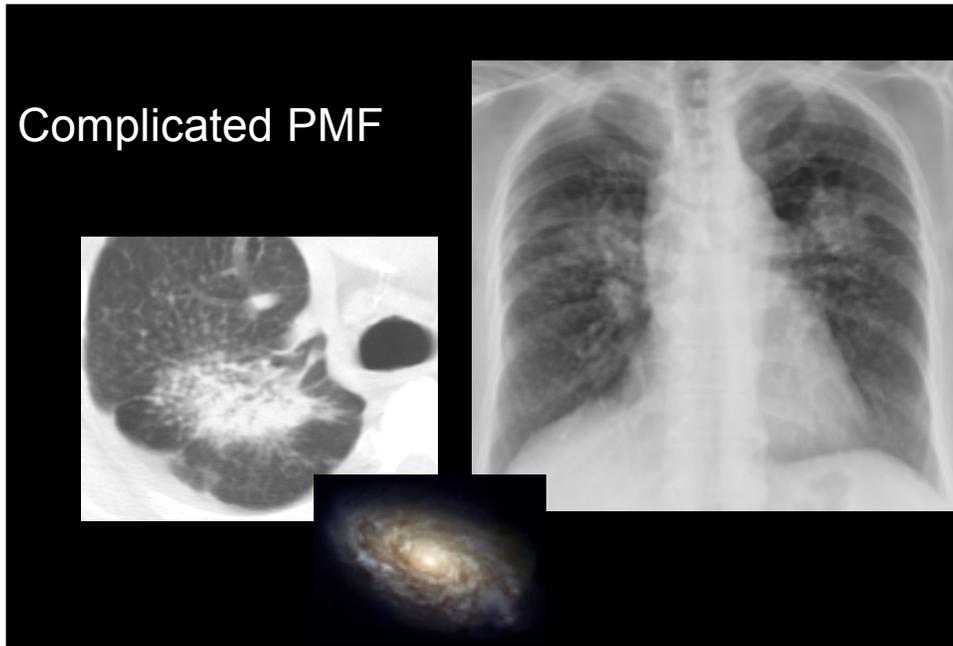
Again, like asbestosis, HRCT is more sensitive and better characterizes the parenchymal changes in the lung. Silicosis is centered on pulmonary lymphatics, thus silicotic nodules are centered along the bronchovascular bundles, centriacinar portion of the lobule, and in the subpleural lung, where the nodules form these pseudoplaques. Nodules are more profuse in the dorsal aspect of the lung and tend to be more profuse in the right upper lung as compared to similar regions on the left.

CWP



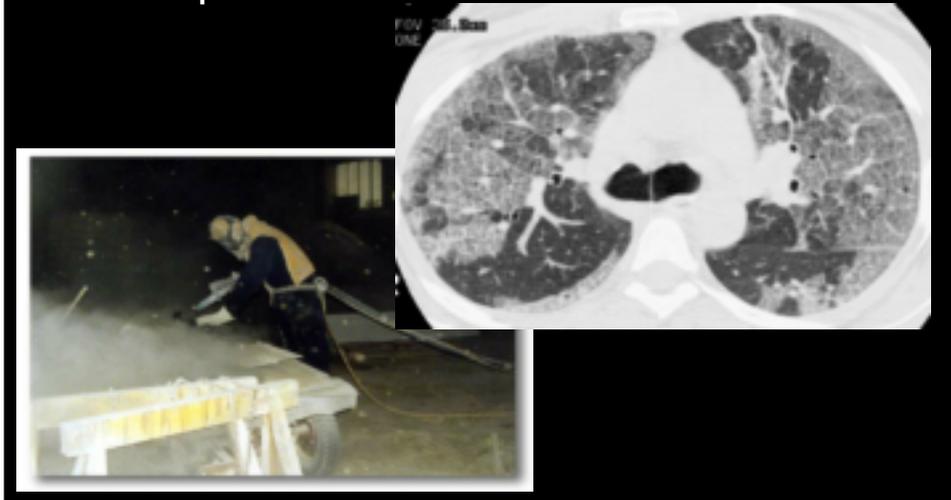
Coal is less fibrogenic than silica. The coal macule, as seen in this macroscopic path specimen is centered on the respiratory bronchiole. Coal is also removed by lymphatics. Note the black pleural line and the black line along the major airways. Note on the HRCT image, in addition to the numerous centriacinar nodules, that the pleura is slightly thickened in this patient with CWP.

## Complicated PMF



Simple silicosis will eventually evolve into PFM, and is generally defined when nodules coalesce into an aggregate more than 1 cm in diameter. Usually the process is bilateral, right greater left in the dorsal aspect of the lung. PMF is lens shaped (wide PA, narrow lateral), and gradually migrates toward the hilum. Overall the whole process looks like a small galaxy. PMF may cavitate, which is problematic because these individuals are at increased risk for tuberculosis.

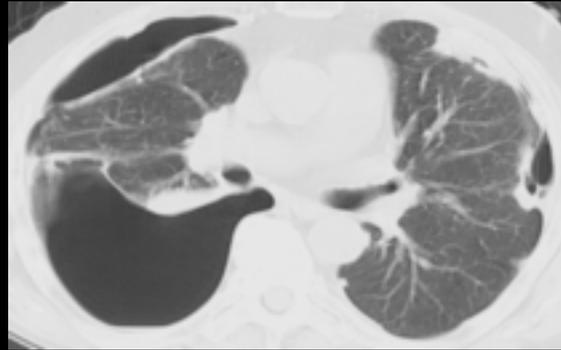
## Silicoproteinosis



Silicoproteinosis is an acute manifestation to overwhelming silica exposure. This usually develops in weeks to months from exposure to high dust concentrations particularly sand blasting in an enclosed space as we see here. Radiographic findings are typical of proteinosis, central bat-wing consolidation and at HRCT, a geographic pattern of ground glass opacities and intralobular reticular lines, the crazy paving pattern. In contrast to PAP, prognosis is poor with limited response to whole lung lavage.

## Caplan's syndrome

Dust + RA + necrobiotic nodules



Finally, coal workers with rheumatoid disease may develop nodules even after relatively low exposures to dust. The lesions are typically subpleural. The lesions may grow rapidly, cavitate and produce a pneumothorax as seen in this patient. Although unusual, Caplans may develop in those with asbestos exposure as seen in this patient.

## Summary

### Rounded dusts

Predominantly upper lung zones

Lymphatic pattern HRCT

### Fibers

Predominantly lower lung zones

Reticular pattern HRCT

In summary, round dusts are handled similarly, and tend to concentrate in the upper lung zones. Nodules tend to aggregate along the lymphatics in the bronchovascular bundle, centriacinar lobule, and subpleural venous plexus. Fibers tend to stay where they are deposited in the lower lung zones. Peripheral reticular fibrosis is the predominant pattern.