Biological Effects of Lunar Surface Mineral Particulates

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Particulate Toxicity

“No pulmonary risks”
Topics

- Relevant mineralogy
- Pulmonary particle handling
- Analog natural diseases
- Experimental lunar toxicology
- Ames dust workshop
Lunar regolith soils are unique
Formed through billions of years of micrometeorite impacts
“Heterogeneous Agglutinitic Glass”
Absence of fluids weathering: very abrasive
Silicate content, grain morphology foci of worry
Pulmonary Particle Handling

Aerosol deposition

- Impaction: >5 \(\mu m\)
- Sedimentation: 0.5-8 \(\mu m\)
- Diffusion: <0.5 \(\mu m\)

Courtesy: Kim Prisk, UCSD
Janelle Fine performing experiments in the KC-135. Photometer and flowmeter are on the platform in front of her. Aerosol was contained in the black bag.
The bolus experiment. A small bolus of aerosol can be introduced anywhere in a controlled breath allowing probing of central (a bolus introduced very late in the breath) or peripheral airways (a bolus introduced early in the breath).
Pulmonary Particle Handling

Total % deposition (DE) as a function of particle size and gravity level (separate panels). The left bar of each pair is the experimental data from KC-135. The right bar of each pair is the deposition predicted from existing models and shows the contributions from impaction, sedimentation and diffusion. For particles around 1 micron, measured deposition is about twice that predicted.

Courtesy: Kim Prisk, UCSD
In microG, very high deposition levels are achieved even though sedimentation is absent. Indeed, for these particles in which sedimentation is thought to be a mechanism of considerable importance, it is clear that other factors dominate.
Aerosols in \( \mu G \)

- Total deposition is unexpectedly high for small particles
  - Small aerosol particles are implicated in adverse health effects of pollutants
  - Suggests transport mechanism(s) that have been previously ignored
- Bolus deposition shows considerable deposition deep within the lung in \( \mu G \)
  - Consistent with the studies of total deposition
  - Suggests that in \( \mu G \) or low-G environments, peripheral deposition is likely very high

Courtesy: Kim Prisk, UCSD
Nanoparticles: Recent interest due to carbon nanotube work; clearance mechanisms unique.

Pulmonary toxicity of any sort of particles $\ll$ 1 micron not well understood.
Analog Natural Diseases

**Pneumoconiosis**
- General term for lung disease caused by inhalation and deposition of mineral dust.
- Can result in crippling or fatal pulmonary fibrosis (one of the worst ways to die)
- Primarily industrial diseases, where offending agents are concentrated from nature
- Big Three: Anthrocosis (black lung; coal miner’s disease), Asbestosis, Silicosis
- All on the decline in the U.S.
Analog Natural Diseases

- Anthracosis (coal miner’s lung; black lung)
Analog Natural Diseases

- Asbestosis
  - “inextinguishable” [Greek]
  - Asbestos is a group of naturally occurring, heat-resistant fibrous silicates
  - Associated with fibrosis and malignancy (bronchogenic carcinoma, mesothelioma)
Analog Natural Diseases

- **Asbestosis pathophysiology:**
  - The cumulative dose, type, durability, and dimensions of the fiber influence carcinogenicity and fibrogenicity.
  - All types of asbestos fibers are fibrogenic to the lungs.
  - Amphiboles, particularly crocidolite fibers, are markedly more carcinogenic to the pleura.
  - Fibers with diameters smaller than 3 micrometers are fibrogenic because they penetrate cell membranes.
  - Long fibers (ie, >5 micrometers) are incompletely phagocytosed and stay in the lungs, setting up cycles of cellular events and the release of cytokines.
  - Oxygen free radicals (eg, superoxide anion, hydrogen peroxide, hydroxy radicals) that are released by the macrophages damage proteins and lipid membranes and sustain the inflammatory process.
  - Individuals probably differ in their susceptibility to asbestosis based on respiratory clearance and other unidentified host factors.
  - Because the development of asbestosis is dose dependent, symptoms appear only after a latent period of 20 years or longer. This latent period may be shorter after intense exposure.
Analog Natural Diseases

- Asbestosis/carcinoma
- Most famous victim: Steve McQueen
  - surrounded by asbestos all his life
  - odd jobs-at construction sites
  - found on movie sound stages
  - brake linings of race cars
  - in the protective helmets and suits worn by race car drivers
Analog Natural Diseases

Silicosis

- Arguably, the most dangerous pneumoconiosis
- “Stone grinder’s disease”: prevalence increased markedly with the introduction of mechanized mining
- A fibronodular lung disease caused by inhalation of dust containing usually crystalline silica (alpha-quartz or silicon dioxide), or its polymorphs (tridymite or cristobalite)
Silicosis: Pathophysiology

- ~1 micron particles generate silicon-based radicals that lead to the production of hydroxyl, hydrogen peroxide, and other oxygen radicals that damage cell membranes by lipid peroxidation and inactivate essential cell proteins.
- Alveolar macrophages ingest the particles, become activated, and release cytokines that recruit other inflammatory cells damaging resident cells and the extracellular matrix, stimulating fibroblasts to proliferate and produce collagen; fibrosis results.
- Silica particles outlive the alveolar macrophages that ingested them, thereby continuing the cycle of injury.
Analog Natural Diseases

Silicosis

- Simple Silicosis
  - may be asymptomatic or may present with exertional dyspnea and cough with sputum production.
  - Differentiating these symptoms from chronic bronchitis and emphysema in a smoker may be difficult.
- Accelerated Silicosis
  - occurs after exposure to larger amounts of silica over a shorter period of time (4-8 years).
  - Inflammation, scarring, and symptoms progress faster in accelerated silicosis than in simple silicosis.
- Acute Silicosis
  - results from short-term (as short as months) exposure to very large amounts of silica.
  - The lungs become very inflamed and may fill with fluid, causing severe shortness of breath and low blood oxygen levels.
  - Acute silicosis follows massive exposure to dust in unregulated environments.

- What does fractional gravity do to the pathophysiology of pneumoconiosis? Unknown.
Analog Natural Diseases

Other Pneumoconioses:


  - [Morphology of pneumoconiosis induced by natural zeolite] [Article in Russian]
  - Kruglikov GG, Velichkovskii BT, Garmash TI. Pneumoconiosis was induced in white rats through intratracheal administration of natural zeolite. It was characterized by intensive phagocytosis of the specks of dust, moderate cytotoxic action on the macrophages, as well as inflammatory processes in the vascular system and alveolar epithelium. Zeolite induced fibrosis did not develop to the extent as in case with quartz induced massive collagen formation.
Experimental Lunar Toxicology

- No full-scale toxicologic studies performed on lunar dust simulants or the Apollo samples.
  - Basic toxicological responses, acute and chronic
  - Synergisms with < 1g, radiation, cabin atmospheres, altered pharmacokinetics/pharmacodynamics of Rx: flight studies
  - Size particles: how good does the life support filtration system have to be? EVA design impacts.
  - Effects on eyes, skin, gastrointestinal system, systemic leakage from lungs (seen with other minerals)

- Small scale animal studies using intratracheal instillation of saline suspensions have shown marked inflammatory response.

- KC-135 fractional G studies (moon, Mars) using rodents planned by UCSD group.

- Because of scarcity of actual lunar samples, focus will be on simulants; but Catch-22: How much fidelity will be required in the simulant for biological studies? Need tox studies to tell.
Biological Effects of Lunar Soils: A Workshop

- March 19-31, 2005
- Sponsored by NASA HQ
- Outputs: white paper on toxicity of lunar dust; recommendations for ESMD precursor missions
- Radisson Hotel, Sunnyvale, CA (near Ames Research Center)
- Speakers: Apollo Astronaut Harrison Schmitt (keynote), David McKay, John James, Carlton Allen, Kim Prisk, others.
- Website will be online soon.

Planetary surfaces present all of the problems encountered in spaceflight, plus a complex set of new unknowns.
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