GEOLOGICAL HEALTH HAZARDS FROM MARTIAN DUST AND APPROPRIATE COUNTERMEASURES FOR THE HUMAN EXPLORATION OF MARS

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Introduction: There are many challenges to achieving NASA’s goal of a human mission to Mars. The technological issues of a Mars mission have been explored through the Mars Exploration Program and will continue to be addressed by early Artemis missions to the moon. Yet complex challenges remain in the field of human health protection. These challenges include adaptations during long duration spaceflight like those seen in missions to the International Space Station, as well as novel health risks that come with planetary surface exploration.

A notable health hazard during Apollo was lunar dust, which was abrasive and noxious to astronauts (Fig. 1). Martian crews will also face this hazard, as dust on Mars is known to be electrostatic, magnetic, abrasive, highly oxidative, chemically reactive, irregularly shaped with rounded edges, and has an average radius of ~1.5 μm or as large as ~4μm during dust storms (Fig. 2) [1-3]. First line defenses to Martian dust exposure include spacesuits and the Martian habitat. Several technologies have been developed to aid the suit and habitat in dust mitigation, including filtration, electrostatic repulsion, and self-cleaning functions [4-6].

These countermeasures aren’t impermeable, however, and breaches will inevitably occur exposing astronauts to noxious dust particles. Scientists have detected numerous potentially toxic minerals and chemicals in Martian dust. We summarize herein the chief recurrent geological health concerns from the literature along with potential treatments and countermeasures.

Geological Hazards & Associated Disease:
Inhalation of Martian dust penetrates physical innate immune defenses of the respiratory tract as mucus in the lungs is not able to expel dust particles <5 μm [8]. The unique geological landscape of this planet and subsequent dust composition introduces a collection of challenging health risks.

Martian dust can contain up to 1% oxychlorine compounds (i.e., perchlorate (ClO₄⁻)) [8], which may lead to aplastic anemia from thyroid impacts. After inhalation, the highly oxidized chlorine is hypothesized to block thyroid function by acting as a competitive inhibitor for the sodium-iodide symporter (NIS) found on the basolateral membrane of thyroid cells. By decreasing NIS efficacy, iodide availability decreases, which can cause growth issues as iodine is a major building block for thyroid hormones [9].

Dust containing a fine-grained silicic acid salt (silicate) covers nearly the entire surface of Mars [3, 10]. Silica inhalation has been found to have an association with adverse respiratory effects (e.g., silicosis), renal effects, immunological effects, and an increased risk of lung cancer [11]. Among these health effects, silicosis has the highest incidence. Silicosis is characterized by irreversible, progressive pulmonary fibrosis leading to restrictive lung disease [12]. Aside from transplantation, there is no cure available for silicosis, thus prevention is a necessity.

It has also been suggested that basaltic dust on the Martian surface may cause even more deleterious health effects than that of pure silicas. By either being immersed in water or via dehydroxylation, basalt produces hydrogen peroxide, and in the presence of ferrous iron, hydroxyl radicals are formed [13]. Hydroxyl radicals are powerful oxidants that can induce oxidative stress and inflammation in the epithelial lining.

Fig. 1. Lunar dust covering astronaut Gene Cernan’s spacesuit during Apollo 17 [6].

Fig. 2. Curiosity’s view of Gale Crater before and during the 2018 global dust storm on Mars [7].
fluid of the lungs, which can progress to various lung diseases [14].

Gypsum deposits are widespread on Mars [15]. Health risks to gypsum occur when large quantities come into contact with mucous membranes [16]. Short-term exposure may cause mechanical irritation or GI blockage following ingestion [17]. Long-term inhalation of gypsum can lead to bronchiolitis, fibrosis, metaplasia, pneumonia [18], and a pathophysiologically similar illness to “black lung” or coal worker’s pneumoconiosis [10], which is an incurable disease similar to silicosis and asbestosis that presents with cough, shortness of breath, chest tightness, and production of black sputum [19].

Chromium, beryllium, arsenic, and cadmium are metals detected in Martian soil that are considered to be hazardous to humans even at low concentrations; however, their actual risk to humans at the concentrations detected from Martian rovers is challenged [1]. Chronic inhalation of hexavalent chromium [Cr(VI)] may also lead to pneumoconiosis [10]. Cr(VI) enters cells through anion transporters and subsequently gets reduced to Cr(III), primarily by ascorbate (vitamin C). Accumulations of Cr(III), which cannot transport in or out of the cell, cause oxidative stress and make Cr-DNA adducts that can lead to chromosome breaks. Inhalation of Cr(VI) can also cause allergic asthma and bronchitis acutely as well as nasal irritation and ulceration, emphyma, and lung cancer chronically [20].

Acute beryllium toxicity presents with bronchiolitis, pulmonary edema, and pneumonitis. Dermatologic contact can cause inflammation of the affected area, leading to irritation, ulceration, and subcutaneous granulomas. Chronic beryllium disease presents similarly to reactivated tuberculosis with shortness of breath, unexplained coughing, fever, night sweats, and weight loss [21].

Cadmium and arsenic are group one carcinogens with both acute and chronic toxic manifestations. Chronic cadmium exposure is associated with nephritis, osteoporosis/osteomalacia, and various lung/cardiovascular diseases, while chronic arsenic exposure may cause neuropathy and other nervous system effects. Both have few effective treatment options, especially once chronic manifestations are present, thus avoidance is essential [22,23].

**Treatments & Countermeasures:** Prevention and removal of dust exposure remains the most effective countermeasure. Filtration technologies need to be effective during Martian dust storms as they are crucial to supporting human life (e.g., in spacesuit and habitat filters) and for in situ resource utilization fuel production systems [24].

Secondarily, it is necessary to prevent disease from any mild chronic exposure. Oral vitamin supplements have been an effective method of preventative care in spaceflight, such as vitamin D supplementation for bone loss mitigation [25]. For Mars exploration, we propose adding other vitamins to the regimen such as potassium iodide for perchlorate exposure and vitamin C for Cr(VI) exposure. For the presentation of acute disease, many large interventions such as surgery are not appropriate for space exploration in the immediate future. Even so, many treatments and medications may be used for the immediate therapy of multiple acute symptoms such as bronchodilators for bronchospasms, gastric lavage and activated carbon for toxin ingestion, and rinses for dermal and ocular exposures.

**Conclusions:** The toxicity of lunar dust was an unpredicted health hazard during the Apollo missions. A mission to Mars does not have the luxury of rapid return to Earth for treatment, nor can it rely on flight surgeon ground support of care due to communication delays of up to 40 minutes round-trip [26]. Surface operations will require a far higher cadence of longer duration extravehicular activity than previous missions to the moon. These risks, together with both prolonged exposure of dust compared to lunar missions and the reduced ability to fight disease after long duration adaptation in microgravity, make the hazard of dust a critical problem to solve for the successful and safe human exploration of Mars.