Necessity of Establishing International Environmental Standards to Prevent Pneumoconiosis on the Moon

Ⅰ. Introduction

Half a century after Neil Armstrong's Apollo 11 arrived on the Moon in July 1969 (Aoto, 2011, p. 96), humanity's geographical area extends beyond the framework of the earth and reaches out to the moon. Humans have built civilization by accumulating a lot of knowledge, discovering resources, and developing them until today. However, as human's lives have become more affluent, humans must also pay attention to the various risks that have emerged in working and living environments that can be hazardous to health. In Japan, the economic growth of the country during the high economic growth period during 1955 to 1973, was accompanied by a variety of pollution and industrial accidents, such as Yokkaichi asthma, Minamata disease and Itai-itai disease. In recent years, like the SDGs Goal. 3 Target 3. 9 (https://sdgs.un.org/goals/goal3) and Goal. 11 Target 11. 6 (https://sdgs.un.org/goals/goal11) advocated by the United Nations, there has been a tendency to emphasize the realization of sustainable development, curbing the pollution of the environment due to industrial development. Thus, as the race for development and resource exploitation on the Moon is expected to be getting up speed, it must also consider how to guarantee health and safety for the people who work and live in that environment.

Now, the lunar surface environment, one of the frontiers of today, as well as the case on Earth, should be considered for the health risks of various types of pollution and poor environment at work and in life. Previous international missions to the Moon have provided a variety of information to show that the lunar surface is partly similar to and different from the Earth's environment. In this paper, it will focus on (1) the risk, definition, history, and difficulty in treating pneumoconiosis (silicosis), (2) the similarity between the crustal composition of the Moon and that of the Earth, and (3) the behavior of powder particles due to the low gravity environment on the Moon, in order to emphasize the need to establish international environmental standards for the prevention of pneumoconiosis on the Moon.

II. Risks of pneumoconiosis (silicosis), its definition, history and difficulty of treatment

On this paper, Pneumoconiosis is a disease that has been a problem on Earth for a long time, and it is claimed to be a risk for the lunar environment as well. Here, it discusses the dangers of pneumoconiosis itself and the difficulty of its treatment, and show the need to establish hygienic environmental standards to prevent the risk of developing this disease on the Moon.

In the first place, pneumoconiosis is caused by the inhalation of fine, water-insoluble dust that stagnates in the air, which damages the cells and tissues inside the lungs and causes collagen and other substances to be deposited in the lungs, reducing the elasticity of the lungs' ability to take in air, thereby irreversibly reducing the ability of the lungs to exchange oxygen and carbon dioxide gas. It differs in pathogenesis from viral diseases such as influenza and colds or bacterial infections such as tuberculosis, and is a traumatic disease in which silicate compounds in the vitreous body or dust made of carbon such as coal, asbestos, or particulates such as aluminum or iron are used to damage the lungs.

For example, one could interpret this as a metal fragment lodged in the body and not easily removed from the lung. It is, in other words, an injury with countless fragments lodged in the delicate tissue. Of course, as long as it is an injury, bleeding and inflammation will occur. Furthermore, since these fragments cannot be removed, there is no hope of recovery to smooth, normal tissue. This is what happens at a microscopic level in the lungs, and that is what pneumoconiosis is.

Another factor that makes the disease irreversible is that it occurs in the delicate tissue of the lungs. The lungs are normally responsible for taking in oxygen from the air it takes in and exchanging it for carbon dioxide, which is essential to human life. The place where the exchange of oxygen and carbon dioxide gases takes place is called alveoli, which are microscopic tissues about 0. 2 mm in size each, and the internal tissue of the lungs is made up of countless numbers of these alveoli, which come together like clusters of grapes. If countless knife-like particles pierce the delicate and vital tissues, and all of these particles cannot be removed because they are microscopic, the patient's prognosis is poor. The only treatment available is symptomatic treatment such as oxygen inhalation therapy, antitussives and expectorants for cough symptoms, and the progression of symptoms is irreversible. Such difficulty in treating pneumoconiosis is the problem of this disease.

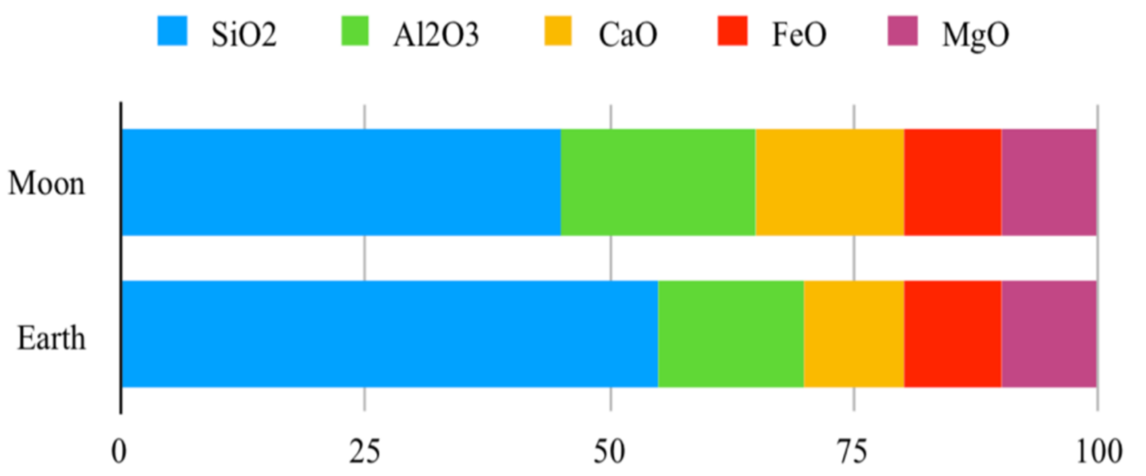
The history of pneumoconiosis as a disease caused by the working environment and other factors is long, and according to Youko Sakaoka, "masks using pig's bladder membranes were invented in the Roman Empire (20s)" to prevent the risk of exposure to dust at work. Therefore, it seems that measures to prevent the risk of exposure to dust at work have been in place since time immemorial. (Sakaoka, 1997, p. 19). Throughout human history, pneumoconiosis has been a problem at work, from masons to miners in the past, and in fiscal year 2019 in Japan, the data for the construction industry (46 cases), ceramic and earthenware manufacturing (35 cases), and mining industry (34 cases) in descending order of magnitude, with the total number of cases reaching 164 per year (Japan Industrial Safety & Health Association, 2020, p. 24-33). It should also be noted that although this figure is less than the annual number of 6015 illnesses caused by injuries, it is not negligible, as it is higher than 51 cases of cerebrovascular and cardiac diseases due to excessive work, 58 cases of mental disorders due to work that involves a high psychological load, and 113 cases of illness caused by pathogens. Hence, it is no exaggeration to say that the risks of pneumoconiosis in the workplace have always existed alongside those of human history and society. As seen in today's home health care setting, it is not hard to imagine that the lives of patients with greatly reduced oxygen uptake would be severely restricted in terms of mobility, movement, and daily life. Even the slightest movement can cause them to be out of breath, as if they had just run at full speed sooner. This is another frightening aspect of pneumoconiosis. Because silica is found in the earth's crust, pneumoconiosis is also common at workplaces in Japan. Therefore, it is important to consider not only how to alleviate the symptoms of diseases for which there is no effective treatment, but also how to manage environmental hygiene to prevent the occurrence of such diseases. Since the lunar work and living environment is as closed as that of the tunnels, the measures for exposure to such dust must be carefully implemented. Because the lunar environment is expected to be different from that on Earth in terms of surgical equipment and inhalation and therapeutic supplies, strict international standards for air hygiene in lunar facilities will need to be established in advance to ensure the universal safety of the people who work and live there.

III. Verification of high pneumoconiosis risk on the lunar surface due to similarities in the composition of the lunar and terrestrial crust

In the previous section II, I explained that measures must be taken to prevent pneumoconiosis on the Moon as well as in the Earth's environment. However, it is necessary to examine whether the dust that is dispersed in the air on the Earth and on the Moon is of the same quality and has the same pathogenicity. In this section, it will show the similarities between the composition of the Earth's and the Moon's crustal composition and discuss the necessity of establishing an international standard for air quality sanitation in the lunar environment to control dust in the lunar environment as well as in the Earth's environment.

According to Masanori Horie, regarding the composition of lunar regolith, the composition of regolith brought back from the moon so far is as follows: SiO_2: 41-47%, Al_2O_3: 10-30%, CaO: 10-17%, FeO: 4-20%, MgO: 4-13% (Horie et al. 2012, p. 238). SiO_2, commonly known as silica, is one of the causative agents of silicosis, a type of pneumoconiosis. According to Eiji Ohtani, the composition of the Earth's crust is roughly SiO_2: less than 60%, Al_2O_3: less than 20%, CaO: 10%, FeO: 10%, and MgO: 10% (Ohtani, 2005, p. 339). The results show that the crustal composition of the Moon and the Earth varies slightly, but the silica SiO_2 accounts for about half of the lunar crustal composition, followed by Al_2O_3, CaO, FeO, and MgO, which are the same as those of the Earth. The risk of developing pneumoconiosis from dust in tunnels and confined spaces on the Moon is expected to be as high as in the Earth's environment.

Figure. 1 Comparison of the crustal composition about the Moon and Earth



Note: The numerical data were taken from these following articles.

Moon crustal composition ratio: (Horie et al. 2012, p. 238)

Earth crustal composition ratio: (Ohtani, 2005, p. 339)

If the composition of dust on the Moon is the same as that on Earth, then pneumoconiosis could occur on the Moon as well. Furthermore, there is no flow of air or water on the Moon. Even if one inhaled the lunar sand on the surface of the Earth, the lunar sand would not be abraded or eroded by wind or water and would remain as dust with its sharp physical structure. This suggests that the lunar sand continues to maintain its sharp physical structure with a high degree of damage to the human body. Therefore, it is necessary to establish environmental health standards for the air in the lunar environment to reduce the risk of human exposure to regolith more strictly in the lunar environment, and to protect the health of people who work and live on the Moon from an institutional perspective.

Ⅳ. The Behavior of Powder Particles in the Lunar Low Gravity Environment and the Higher Risk of Pneumoconiosis in the Lunar Environment Compared to Earth

In the previous sections II and III, it showed the severity of pneumoconiosis and the possibility that pneumoconiosis may occur on the Moon as well as in the Earth's environment. This time, I will discuss the necessity of establishing international environmental health standards for the lunar environment in the future development of the lunar surface, proving that the human body is more likely to be exposed to dust in the lunar environment than in the earth's environment.

The gravitational acceleration of the moon is about 1. 6 m/s^2, which is about one-sixth of the earth's 9. 8 m/s^2. Gravity means the force that attracts an object to the earth, and the stronger this force is, the stronger and faster the object can be pulled to the earth. Normally, the calculation of fall speed with gravity can be expressed as “ $v = g \cdot t$ " (v: fall speed, g: gravity acceleration, t: time). This shows that gravity is proportional to the fall rate of an object under normal circumstances, and the fall rate of an object on the surface of the Moon, where the acceleration of gravity is lower than on the Earth, is expected to be lower and take longer to reach the surface. Now, it considers the case of microscopic particles such as powder. When calculating the settling velocity of a small particle like powder, it is necessary to verify it after taking into account the factors related to air resistance.

According to Yasuo Morimoto, the size of inhalable particles on the earth is less than 10 μm (PM10), while on the moon, the size of particles of 25 μm are considered to be a risk of inhalation. Thus, it is noteworthy that the range of particles at risk of health problems on the Moon is much wider than on the Earth (Morimoto and Horie, 2014, p. 76). Normally, the falling velocity of powder particles can be calculated by the Stokes equation, which takes into account the density of air and particle size (Okada, 1992, p. 16-21). In this article, it will use the Stokes equation to compare the gravitational acceleration of GEarth and GMoon in the earth and lunar environments, respectively, to see how the falling speed of these particles

Figure 2. Comparison of dust settling rates between the Moon and Earth environments using the Stokes formula

The following equation obtained from the Stokes equation is used.

$$Vt = (G (\rho p - \rho a) / 18 \mu a) Dp^2$$

$$\rho p > \rho a , \ G_{Earth} > G_{Moon}$$

$$(G_{Moon} (\rho p - \rho a) / 18 \mu a) Dp^2 < (G_{Earth} (\rho p - \rho a) / 18 \mu a) Dp^2$$

Therefore,

$$Vt_{Moon} < Vt_{Earth}$$

Vt	：Falling speed of an object (cm/s)	μa	：Viscosity coefficient of air (g/cm・s)
Vt Moon	：Falling velocity of powder on the moon (cm/s)	Dp	：Grain diameter (cm)
Vt Earth	：Falling velocity of powder on earth (cm/s)	ρp	：Density of particles (g/cm^3)
G	：Gravitational acceleration (cm/s^2)	ρa	： Density of air (g/cm^3)
G Moon	：Gravitational acceleration on the moon (cm/s^2)		
G Earth	：Gravitational acceleration on Earth (cm/s^2)		

As above, it was found that the falling velocity of VtMoon is lower than that on the earth, and the powder remains in space for a longer period of time. This indicates that the risk of human exposure to dust is higher on the Moon than on the Earth. Therefore, it must ensure that air quality measurements and countermeasures are implemented for dust at lower levels on the Moon than the environment on Earth. And in order to achieve this, it will be necessary to establish international environmental standards for the prevention of pneumoconiosis in the lunar environment in order to achieve universal protection of human life working and living on the Moon.

Ⅴ. Conclusion

So far, it has mentioned that in the lunar environment, various factors such as the presence of lunar sand that is called regolith and low gravity can cause irreversible and serious diseases called pneumoconiosis. In addition, because the lunar facility is an enclosed space like a tunnel, the air in this vacuum environment needs to be constantly monitored, and concrete measures such as the wearing of dust masks with electric fans and the introduction of air cleaning filters are required to prevent exposure to the lungs from dust. Therefore, the need to establish international environmental standards for the prevention of pneumoconiosis on the Moon will increase in the future.

As the development of the Moon progresses, more people will have the opportunity to visit the Moon in the future. In such a situation, it is necessary to look back on the various occupational accidents and health and safety measures in the history of the Earth and to take preventive measures to protect people universally, regardless of race or gender, with a view to continuously exploring the frontier. Finally, the SDGs Goal. 12 Target 12. 8 (https://sdgs.un.org/goals/goal12) proposed by the United Nations clearly state "People everywhere". This means that measures will be needed to protect all people, not only on the Earth but also on the Moon.

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