Toxicity of Lunar Volatiles on Human Health

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1. Abstract

– The exploration and commercialisation of the Moon intends to utilise the lunar resources to support human habitation and the lunar economy. These resources, including lunar volatiles, can adversely impact human health. Using the concentration of lunar volatiles detected in the Cabeus crater ejecta as an analogue, this research determines the mass of lunar volatiles acting as contaminants in spacecraft drinking water and spacecraft atmospheres that can result in NASA's spacecraft safe exposure limits being exceeded. The research determines that lunar volatiles concentrations as low as 0.87% of ethylene, 0.26% of methanol and 0.0083% of ammonia within lunar regolith can contaminate drinking water beyond safe exposure limits, and 0.75 grams of lunar regolith contains sufficient lunar volatiles to exceed safe airborne exposure limits per cubic metre of atmosphere.

2. Introduction

– The detection of water and other volatiles in the Cabeus crater ejecta (Table 1) [1] has provided an opportunity to utilize lunar in-situ resources, as water and oxygen sources for human settlements, building materials and fuel [2-4]. Many of these same volatiles are toxic to humans and exposure to low concentrations can result health implications.

The National Aeronautical and Space Administration's (NASA's) Artemis III mission is to return humans to the Moon by 2026, landing in the lunar south pole [5]. One of the seven overarching science objectives of this mission is to understand the character and origin of lunar polar volatiles, with humans performing in situ measurements and returning volatile bearing lunar samples to Earth for further scientific analysis [6]. To ensure the safety of all personnel transporting and handling the regolith, the effects of any contaminants within the sample are to be understood with safety protocols established in the event of an accidental release of and human exposure to the lunar volatiles. Furthermore, technologies to extract drinking water and oxygen from lunar regolith are being explored [7-9]. These technologies are to ensure the contamination of water and oxygen by toxic volatiles in concentrations that exceed safe water and atmospheric guidelines can result in human health implications are not exceeded.

To ensure the safety of all humans in spacecraft, NASA's Human Health and Performance Directorate have established Spacecraft Water Exposure Guidelines (SMEGs) (JSC 63414) [10] and Spacecraft Maximum Allowable Concentrations (SMACs) for Airborne Contaminants (JSC 20584) [11] for spacecraft environments outlined in NASA's Spaceflight Human-system Standard Volume 2: Human Factors, Habitability, and Environmental Health (NASA-STD-3001) [12]. These guidelines provide maximum concentrations of known toxins in drinking water and spacecraft atmospheres where humans could have long-term exposure to the volatiles without a reprieve to expel toxins. Continuous exposure limits are provided for short-, medium- and long-term human exposure.

Compound	% Relative to H_2O
H_2O	100.00
H_2S	16.75
NH_3	6.03
SO_2	3.19
C_2H_4	3.12
CO_2	2.17
CH_3OH	1.55
CH_4	0.65

Table 1: Volatiles detected in the Cabeus crater ejecta [1].

3. Results

Lunar Volatiles as Contaminants in Water

For the volatiles detected in the Cabeus crater ejecta (Table 1), three volatiles have established SWEGs: ammonia, ethylene and methanol (Table 2). Using the concentration of lunar volatiles detected in the Cabeus crater ejecta in Table 1 as an example, assume all of the water within a sample of lunar regolith was to be extracted for human consumption. To extract 1 litre, or 1,000 grams, of water from lunar regolith containing a water concentration of 5.6 wt %, 17,857.1 grams of lunar regolith will be required, assuming 100% of the water is extracted.

The mass of ammonia, ethylene and methanol found within the 17,857.1 grams of lunar regolith was determined (Table 3). And the percentage of volatiles within the lunar regolith to make 1 litre of water that can contaminate the water before exceeding was calculated using the SWEG values divided by the mass of volatiles within the lunar regolith (Table 3).

Contamination of very small concentrations of volatiles, less than 1% by mass, in drinking water can exceed NASA's SWEGs (Table 3). For short term exposure limits of less than 1 day, 0.0083% of ammonia, 0.864% of ethylene or 0.258% of methanol by mass of the volatiles within the lunar regolith will exceed NASA's SWEGs. For long-term continuous exposure of volatiles, up to 1000 days, within the spacecraft drinking water, these exposure limits reduce to 0.0017% for ammonia and 0.0128% of ethylene, with methanol remaining at 0.258%.

Volatile	1 day (mg/L)	10 days (mg/L)	100 days (mg/L)	1000 days (mg/L)
NH_3	5	1	1	1
C_2H_4	270	140	20	4
CH_3OH	40	40	40	40

Table 2: NASA's SWEGs for volatiles detected in the Cabeus crater ejecta [10].

Volatile	Volatile in lunar regolith sample (g)	1 day (%)	10 days (%)	100 days (%)	1000 days (%)
NH_3	60.36	0.0083%	0.0017%	0.0017%	0.0017%
C_2H_4	31.25	0.864%	0.448%	0.0640%	0.0128%
CH_3OH	15.50	0.258%	0.258%	0.258%	0.258%

Table 3: The mass of lunar volatiles found in 17,857.1 grams of lunar regolith, and the amount of each volatile that will result in volatiles reaching NASA's SWEGs.

Lunar Volatiles as Airborne Contaminants

Of the volatiles in Table 1, five volatiles have established SMAC's: hydrogen sulphide, ammonia, carbon dioxide, methanal and methane (Table 4). For the analysis of this research, only volatiles with exposure limits in parts per million will be analysed. Using the concentration of lunar volatiles detected in the Cabeus crater ejecta in Table 1 as an example, assume all of the volatiles within a sample of lunar regolith will dissipate immediately as airborne contaminants when exposed to spacecraft atmospheric conditions. Using Equations 1 and 2, the maximum allowable mass of lunar regolith containing volatiles that can be exposed to spacecraft atmospheric conditions before exceeding SMAC limits can be calculated.

The results (Table 5) found in the concentrations found in lunar samples from the Cabeus crater, very low masses of lunar regolith containing hydrogen sulphide and ammonia will exceed continuous spacecraft exposure limits for airborne contaminants, with 0.75 grams of lunar regolith able to exceed the maximum exposure limits. For long-term continuous exposure, up to 1000 days, the maximum mass of regolith containing lunar volatiles can be as low as 0.04 grams per m³ of spacecraft atmosphere.

Equation 1: $$mg/m^3 = ppm\frac{(MW_i)P}{RT}$$

Equation 2: $$Weight\ percent(wt\ \%) = \frac{Mass_i\ (g)}{Mass_{Regolith}\ (g)}$$

Volatile	1 hour (ppm)	24 hours (ppm)	7 days (ppm)	30 days (ppm)	180 days (ppm)	1000 days (ppm)
H_2S	5	1.3	1.3	1.3	0.3	NA*
NH_3	30	20	3	3	3	3
CO_2	-------------- Partial pressure to not exceed hourly average of 3mmHg -------------					
CH_3OH	70	70	20	20	20	10
CH_4	10% LEL	10% LEL	10% LEL	10% LEL	10% LEL	10% LEL

Table 4: NASA's airborne contaminants SMACs for volatiles detected in the Cabeus crater ejecta [11]

Volatile	1 hour (g/m³)	24 hours (g/m³)	7 days (g/m³)	30 days (g/m³)	180 days (g/m³)	1000 days (g/m³)
H_2S	0.74	0.19	0.19	0.19	0.04	NA*
NH_3	6.2	4.1	0.62	0.62	0.62	0.62
CH_3OH	105.6	105.6	30.2	30.2	30.2	15.1

Table 5: Maximum mass of regolith in grams (g) containing concentrations of volatiles similar to the Cabeus crater ejecta that can safely be handled in 1 m³ volume before exceeding maximum long term continuous exposure limits. Atmospheric conditions as per NASA-STD-3001 assuming 25°C and 1 atmosphere pressure, inspired partial pressure of oxygen at 2.90 psia and a single volatile is exposed to the atmosphere at a time.

4. Conclusion

– By identifying and limiting human exposure to lunar regolith from areas on the Moon that could contain volatiles that are toxic to human health, the risk to human health can be minimized. The selection of locations that do not contain hazardous volatiles can aid lunar exploration missions identify areas that are more suitable to extract volatiles for human settlements, and help water and air purification systems be tailor made for the lunar environments in which they will be deployed, making lunar missions more affordable and cost effective.

The same learnings from this study can be used on Earth and on any extra-terrestrial body. Further research into how lunar volatiles exist and migration paths that can impact contamination of water and atmospheres is required.

References

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