Measurements of the radioactive activity of Mars

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Abstract

The prospective colonization of celestial bodies, Mars in particular, presents a significant challenge due to radiation exposure. Radiation originates from cosmic sources and Martian isotopes, posing risks of contamination and irradiation. This interaction deposits energy, quantified as dose (D), impacting DNA and cellular functions, with potential consequences like acute effects, cancer risk, and neural-cardiovascular issues. Remediation involves temporal, spatial, and shielding strategies. This study aims to comprehensively characterize radioactivity through direct measurements, isotope analysis, and passive dosimetry. The goal is to inform strategies for health and mission success during interplanetary exploration.

1 Introduction

The eventual colonization of extraterrestrial bodies, commencing with those within our solar system, holds an undeniable prospect for the future of humanity. Mars, in particular, stands as a pivotal target for interplanetary habitation. However, this audacious endeavor presents an array of formidable challenges, with radiation emerging as a formidable concern. The perils of this undertaking extend beyond technological and human accomplishments, encompassing the intricate hazards posed by radiation exposure. This radiation originates from dual sources : cosmic radiation pervading space and radioactive isotopes intrinsic to the Martian soil.

The peril posed by radiation exposure can be broadly categorized into two distinct yet interrelated phenomena : contamination and irradiation. Irradiation entails the direct outcome of external interaction between an entity and ionizing radiation. This effect subsides as the entity moves away from the radiation source. In contrast, contamination transpires when radioactive substances adhere to an entity or object, or are inhaled or ingested. In such instances, a continuous and enduring production of radioactivity prevails until the source of contamination is eradicated.

In either scenario, the interaction of radiation with biological matter culminates in the deposition of energy, quantified as a dose (D). The dose describes the energy (E) deposited per unit mass (m) and is encapsulated by the equation :

$$D = \frac{\mathrm{d}E}{\mathrm{d}m} \tag{1}$$

This deposition of energy exerts consequential effects upon DNA and cellular functions, ushering forth an array of potential risks. These encompass acute in-flight effects, chronic cancer risks, and the manifestation of central nervous system and cardiovascular complications, all of which could jeopardize mission success and necessitate meticulous consideration [2].

Thankfully, avenues exist for mitigating radiation dose exposure. Three pivotal factors can be manipulated : duration of proximity to the radiation source, spatial separation from the source, and the implementation of shielding materials between the radiation source and the exposed entity.

The central goal of this study resides in the comprehensive characterization of an expansive region from a radioactivity perspective. This entails both direct measurement, quantified in counts per second, and isotope analysis. Additionally, the deployment of passive dosimeters will facilitate the measurement of personal doses, contributing to a comprehensive understanding of the radiation landscape. Through these endeavors, a more nuanced comprehension of the radiation environment can be achieved, fostering informed strategies for safeguarding the health and mission success of future extraterrestrial explorations.

2 Methods and materials

This experiment was partitioned into three distinct sub-experiments, each aimed at investigating specific dimensions of radioactivity. Through this structured approach, a comprehensive analysis of diverse radiological aspects was pursued.

The first sub-experiment centered on quantifying radiation exposure encountered during the mission. Dosimeters were employed to accurately measure received doses, enhancing our comprehension of the mission's radiation environment.

Figure 1 – NaI scintillator (left) and personal passive dosimeter (right) [3].

The second sub-experiment focused on assessing radioactivity inherent to Martian soil. This examination provided insights into the planet's radiological composition, crucial for understanding its overall radiation profile.

The third sub-experiment involved a meticulous analysis of collected samples, aimed at differentiating various radioactive isotopes present within. This endeavor deepened our understanding of the radiological landscape and its potential implications.

2.1 Experiment 1

This experiment elucidates the assessment of radiation exposure among aircrew members through the utilization of passive dosimeters distributed across various locations. Each of the 8 crew members was equipped with a passive dosimeter (figure 1). To facilitate the quantification of the received dose, dosimeters were strategically placed in different settings, including the originating country (Belgium), within the station, outside the station, and beneath the ground, enabling comprehensive evaluation of radiation dose reception. This enabled quantification of the received dose in the following ways :

1. On the airplane (Ext-Bel)
2. For each individual, excluding the airplane (Perso-(Ext-Bel))
3. Inside the station, considering the shielding (Ext-Int)
4. Outside the station, taking into account the natural shielding (Ext-Ent)

All but one of the dosimeters passed through customs.

2.2 Experiment 2

Radiation detection is essential for assessing the presence and distribution of radioactive isotopes in various environments. This experiment focuses on the integration of gamma radiation point measurements, into a three-dimensional drone-based survey. The utilization of point measurements in conjunction with drone technology enhances the spatial resolution and accuracy of radiation mapping.

A solid scintillator, NaI (figure 1), was employed for the acquisition of point measurements of gamma radiation. This scintillator was specifically selected due to its capability to detect gamma radiation emissions, enabling the identification of gamma-emitting radioactive isotopes. The radiation activity was quantified in counts per second, providing a measure of radiation intensity.

A total of 528 point measurements were conducted, each assigned specific GPS coordinates. The trajectory followed during these measurements adopted a snake-like pattern, enabling comprehensive coverage of the target area.

2.3 Experiment 3

Radiological assessment of materials is essential to characterize their radioactive content and their potential impact on living beings. This study concentrates on the spectral analysis of samples extracted from a hotspot of interest, focusing on the identification and quantification of isotopes present within the samples. Such analysis aids in revealing the nature and source of radiation in the hotspot area.

Three distinct samples were collected to facilitate comprehensive analysis : a reference sample representing a background radiation level, a sample from the identified hotspot, and a sample from a fossil discovered on-site, which exhibited elevated radioactivity. These samples were chosen to encompass a spectrum of radiation intensities and potential isotopic compositions.

The extracted samples were transported to the UCLouvain GeLi lab in Louvain-La-Neuve, Belgium, for detailed spectral analysis. Spectrometry techniques were employed to discern the energy levels and intensities of emitted gamma radiation, providing insights into the isotopic composition of the samples.

3 Results and discussion

3.1 Experiment 1

Understanding radiation exposure through passive dosimeters is essential. In this study, we analyzed dosimeter data from individuals after returning to Belgium. We used dosimeters on people and in various places like indoors and outdoors for comparison.

Unfortunately, clear patterns or correlations within the dosimeter data were not identified. A significant part of the radiation exposure came from airport baggage scanning. Some dosimeters that weren't scanned showed no radiation at all. Even though our dosimeters were sensitive enough, they didn't detect any radiation in these cases.

Differences in dosimeter readings were noticeable among those that went through baggage scanning. These differences happened because of how the dosimeters were placed and oriented in the luggage during scanning.

To address these issues, we suggest two alternatives. First, using more sensitive dosimeters could help detect even tiny radiation doses, avoiding the need to pass them through airport customs. Second, placing dosimeters carefully in luggage to ensure an even radiation dose distribution. Additionally, at Schipol airport, which uses CT scanners [1], it's crucial to avoid metallic objects in luggage that could weaken X-ray intensity and lead to varied radiation doses.

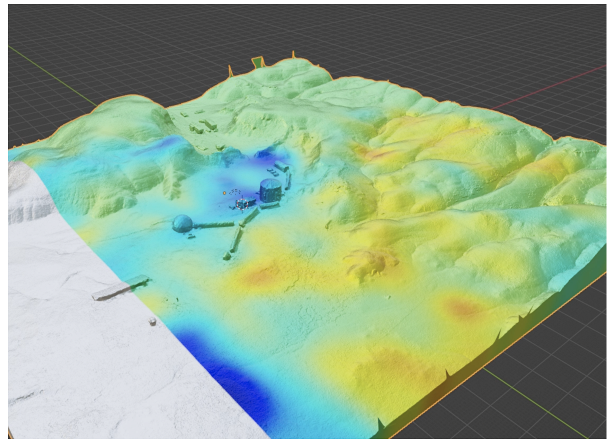

Figure 2 – 3D map of the radioactivity at the Mars Desert Research Station. The color gradient employed in the visualization employs blue hues to denote regions with low radioactivity levels, while areas characterized by high radioactivity are depicted using red shades.

3.2 Experiment 2

The 3D radioactivity map can be seen in figure 2.

In the pursuit of comprehending radioactivity distribution, quantitative analysis of measured counts per second assumes significance. This investigation captured a spectrum of counts per second, with a minimum of 10 and a maximum of 25. Evidently, regions characterized by heightened human activity, such as proximate to the base, and areas with a topographically flat terrain manifest comparatively lower radioactivity levels. In contrast, regions exhibiting heightened radioactivity correspond to elevated terrain features. A plausible conjecture is that wind-driven dust may accumulate in the lower-lying regions, affording protection from wind-borne dispersion.

The computed average counts per second

1. NUCTECH XT2080AD[1]

Isotope	Mars	Fossile
K-40	1.72	1.51
PB-210	/	6.023E-002
BI-212	6.068E-002	8.013E-002
PB-212	2.97E-002	1.22E-002
BI-214	6.68E-002	6.68E-002
PB-214	/	4.33E-002
U-235	/	8.48E-003

Table 1 – Isotopes identified with a confidence index greater than 0.5. The measurements represent the average activities weighted with respect to each decay energy in [Bq/g].

stood at 17.59, offering a representative measure of radioactivity within the surveyed area. It is imperative to underline that these measurements primarily pertain to background radiation, with no discernible presence of radioactive sources.

In light of these findings, spot measurements emerge as a prospective avenue to inform the selection of a suitable base location, thereby mitigating astronaut exposure to radiation. By targeting regions characterized by diminished radioactivity, an optimal site selection strategy could minimize potential radiation dose to astronauts.

3.3 Experiment 3

Our scientific analysis revealed a wide variety of isotopes throughout the course of eight hours and gave crucial information on two different families of decay, the uranium and thorium series.

The isotopes in the thorium series comprised BI-212 and PB-212, while the isotopes in the

Isotope	Bruxelles	Wallonie
K-40	2.24	1.004
BI-212	1.34E-001	9.42E-002
BI-214	/	9.48E-002
PB-214	/	6.43E-002

Table 2 – Isotopes identified with a confidence index greater than 0.5. The measurements represent the average activities weighted with respect to each decay energy in [Bq/g]. Samples were collected in Woluwé-Saint-Pierre and Dinant for Bruxelles and Wallonie respectively.

uranium series included PB-210, BI-214 (a radon daughter), and PB-214 (another radon daughter). Obviously, all these isotopes were found in very small quantities and therefore pose no danger to humans.

Furthermore, the K40 isotope, a naturally occurring radioisotope, was also thoroughly examined in this study. Becquerels per gram (Bq/g) measurements of K40 showed higher values in Brussels, which were explained by the presence of dirt in the sample, primarily consisting of three main isotopes of nitrogen, phosphorus, and potassium (NPK), which are typically found in soil.

4 Conclusion

In this scientific exploration, encompassing three distinct experiments, we have ventured into the intricate world of radiation exposure, radioactivity distribution, and the presence of various isotopes in diverse settings. Each experiment provided a unique perspective on these phenomena, yielding valuable insights and implications.

Experiment 1 reinforced the importance of comprehending radiation exposure through passive dosimeters. While the data did not reveal clear trends or correlations, it was evident that airport baggage scanning contributed significantly to recorded radiation doses.

Experiment 2 illuminated the distribution of radioactivity at the Mars Desert Research Station, ascertaining variations in radiation levels across different areas. Lower radiation activity was noted in regions near the base, while elevated activity was observed in areas with distinct terrain features. The accumulation of wind-driven dust in lower-lying regions was suggested as a contributing factor to these variations.

Experiment 3 examined isotopic activity in Mars and terrestrial samples, uncovering a diverse array of isotopes. These isotopes, while present in the samples, were typically at low concentrations, posing no significant risk to human health.

The results of these investigations provide radiation science with both practical and theoretical advancements. The conclusions and recommendations made here have the potential to improve radiometric measurements, site selection, and radiation monitoring for futur space exploration.

Acknowledgement

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