Symposium

Volume 4 | Issue 1 Article 4

Radiation Exposure During Space Travel: Using Radioisotopes for a Comparative Study of Human Feces and Urine as Integrated Shield Components

Noah L. Falck
California Polytechnic State University, San Luis Obispo

aerospace
142
As
98.638

Radiation Exposure During Space Travel: Using Radioisotopes for a Comparative Study of Human Feces and Urine as Integrated Shield Components

By Noah Falck

Abstract

Earth's atmosphere and magnetosphere deflect and absorb the majority of harmful radiation traversing space; however, once outside Low Earth Orbit (LEO), payloads are exposed to Galactic Cosmic Rays (GCR) and Solar Particle Events (SPE). While humans possess capabilities that hardware does not, we are uniquely vulnerable to radiation. Detrimental effects range from nausea and dizziness brought by intense, short-term doses to increased cancer risk and impaired cognitive function associated with chronic exposure. This paper aims to explore the use of human waste (feces and urine) as radiation shields in a comparative study of urine vs. water and hydrated vs. dehydrated feces. GCRs contain particles with energy orders of higher magnitude than SPEs, which makes them impractical to shield against. Conversely, SPEs occur with higher frequency and at a lower level that is practically attenuated. To this end, an SPE surrogate was validated and exposure (Counts) on the leeward side of the respective shields was measured. Counts per Minute (CPM) were obtained by applying a multiplicative factor to Counts. As expected, CPM behind a urine shield did not differ from CPM behind a water shield (t-test, $p < 0.05$). Similarly, no difference in leeward CPM was found between hydrated and dehydrated feces shields (t-test, $p < 0.05$). The lack of differences between water and urine may be a result of urine being primarily composed of water. While fecal matter is made primarily of water as well, the solid content likely masks the loss of water's attenuation properties.

Acronyms

CPM Counts per Minute

GCR Galactic Cosmic Ray

GMW Geiger-Mueller tube window

HIMAC Heavy Ion Medical Accelerator in Chiba

LEO Low Earth Orbit

OLTARIS Online Tool for Assessment of Radiation in Space

RI Radioisotope

SPE Solar Particle Event

Introduction

As humans continue to travel farther from Earth to explore space, we encounter a Pandora's box of biological hazards. Chief among dangers to *Homo sapiens* is the damage caused by radiation (Horneck et al., 2006), which can be classified into two main categories: acute and chronic symptoms. Acute symptoms include nausea and vomiting and are typically the result of exposure to a high dose during a short timespan. Chronic symptoms vary from increased cancer risk to cataract development (Langford, n.d.) and are associated with prolonged exposure to radiation. With space travel, there are two 1,000 lb gorillas in the room: mass and money. This paper will involve the former. The mass limitation requires that waste is minimized and that many materials serve multiple purposes, such as the use of drinking water as part of a Solar Particle Event (SPE) shelter (Simon, Clowdsley, & Walker, n.d.). While humans possess capabilities hard payloads do not, they bring their own set of limitations.

One of the commonly accepted characteristics of life is the production of waste; during a long-term mission such as the journey to Mars and back, biological waste will be an influential factor. Approximately 128 g of feces wet mass and 1.4 L (59 g dry solids) of urine are produced by each human daily (Rose, Parker, Jefferson, & Cartmell, 2015). With a crew of six and an estimated Earth-Mars transfer of 202 days (Horneck et al., 2006), such approximations predict 155 kg of feces wet mass and 1,697 L of urine (72 kg dry solids) produced upon Martian arrival. Consequently, biological waste will be a factor that cannot be ignored. Given that waste and radiation are two immovable constants, this paper aims to explore the idea of using human waste as a radiation shield.

While urine is primarily recycled for potable liquid and oxygen production (Jr., Carter,& Higbie, n.d.), feces have not been similarly utilized. For expeditions outside Low Earth Orbit (LEO), storm shelters will likely integrate compacted foodstuffs, equipment and biowaste (Simon et al., n.d.). Therefore, this investigation will explore the comparative qualities of urine and feces as elements of such a shield. Urine is primarily composed of water, which will likely result in no significant difference in attenuation compared to pure water. Human feces are composed of approximately 75% water and 25% solid matter (Britannica, 2002), which suggests a possibly significant negative effect on its attenuation properties after desiccation. Because the high energies required to directly simulate SPE particles would be impractical to achieve in the Space Environment Laboratory of California Polytechnic State University, San Luis Obispo, a surrogate must take the place of a particle accelerator.

While the β decay (two protons and two neutrons) of radioisotopes (RIs) occurs at orders of magnitude below that of SPEs, they are composed of similar particles: protons (Simon et al., n.d.); therefore, they may produce similar exposure effects on the leeward side of a shield. In order to determine if RIs may be used as SPE surrogates, they will be tested against shielding scenarios predicted by NASA's Online Tool for the Assessment of Radiation in Space (OLTARIS). The RIs that can replicate the trends to a statistically significant level will be used for the aforementioned experiments.

Materials & Methods

Hardware Specifications and Data Analysis

A glass vial of 0.87 in. inner diameter was placed in front of the Geiger-Mueller tube window (GMW) for all tests, which provided an effective shield thickness of the vial's inner diameter. The Geiger counter used was a Vernier® Digital Radiation Monitor connected to a Vernier® LabQuest Mini. Count measurements were collected at 10 s intervals for the respective timespans. Counts were then multiplied by a factor of six to convert to Counts per Minute (CPM). Statistical analysis was performed on the CPM data with MATLAB R2015b and Microsoft® Excel 2016.

Radioisotope Specifications

Three radioisotopes used included: 1 μCi. Co-60, 5 μCi. Cs-137 and 0.1 μCi. Po-210. All were in the form of discs acquired from Spectrum Technologies.

Radioisotope Surrogate Validation

The shielding scenario used for RI surrogate verification was a comparison of Aluminum-High Density Polyethylene (Al-HDPE) and High Density Polyethylene-Aluminum (Slaba et al., 2011). Two layers of 0.002 in. thick Al sheeting were combined with one layer of 0.004 in. thick HDPE to create a 0.008 in. thick Al-HDPE shield that was placed adjacent to the GMW on a Vernier Digital Radiation Monitor (**Fig. 1**). Each radioisotope (Co-60, Cs-137, and Po-210) was placed one in away and two 90 s exposures were taken for each shield configuration: Al-HDPE-GMW and HDPE-Al-GMW. A two-sample t-test at $\alpha = 0.05$ was run for each scenario pair to determine if any differences were significant. The RI(s) that were validated as surrogates were then used for the urine and feces tests.

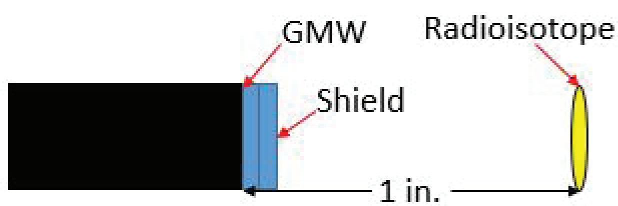

Figure 1: RI surrogate validation schematic. The 0.008 in. shield (both orientations) is adjacent to the GMW that is 1 in. from the RI (Co-60, Cs-137 and Po-210).

Urine-Water Shielding

The validated RI was placed three in. from the GMW and the vial of urine/water stood adjacent to the GMW. The vial was constant through all liquid tests, allowing analysis of CPM without compensation for the glass walls. The vial was filled with water and a 10 min exposure was recorded; the same procedure was followed for urine, which was used within 10 min of sample collection. Both fluids were above the top of the GMW, ensuring complete coverage relative to the RI **(Fig. 2)**. A two-sample t-test at $\alpha = 0.05$ was run between both scenarios to determine if there were any significant differences in shielding effectiveness.

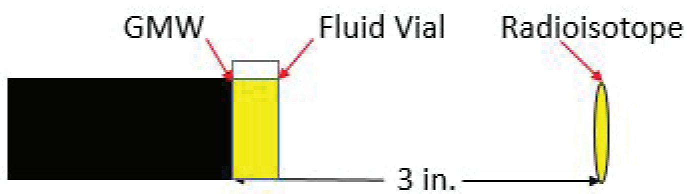

Figure 2: Urine/Water test schematic. The fluid-filled vial stood adjacent to the GMW, and the RI 3 in. from the GMW

Hydrated - Dehydrated Feces Shielding

The validated RI was placed three in. from the GMW and the vial of feces stood adjacent to the GMW. The vial was constant through both tests, allowing analysis of CPM without compensation for the glass walls. The vial was filled with feces and a 10 min exposure was recorded. The feces were left in the vial, placed in a vacuum chamber and exposed to pressures of approximately 490 mTorr. After desiccation, the sample was removed from the vacuum chamber and a 10 min exposure was recorded. Both feces levels were above the top of the GMW, ensuring complete coverage relative to the RI **(Fig. 3)**. A two-sample t-test at $\alpha = 0.05$ was run between both scenarios to determine if there were any significant differences in shielding effectiveness.

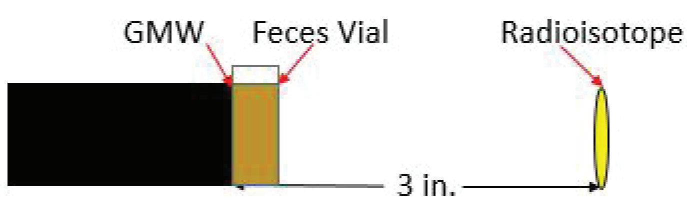

Figure 3: Hydrated and dehydrated feces test schematic. The feces-filled vial stood adjacent to the GMW, and the RI 3 in. from the GMW.

Results

Radioisotope Surrogate Validation

Out of the three RIs tested (Co-60, Cs-137 and Po-210), only Cs-137 exhibited a difference between Al-HDPE and HDPE-Al shields ($p < 0.05$). As shown in **Fig. 4**, the Al-HDPE orientation reduced CPM on the leeward side of the shield compared to the HDPE-Al orientation. Cs-137, being the only β emitter that mirrored the OLTARIS results (Slaba et al., 2011), positioned it as the RI surrogate for further tests.

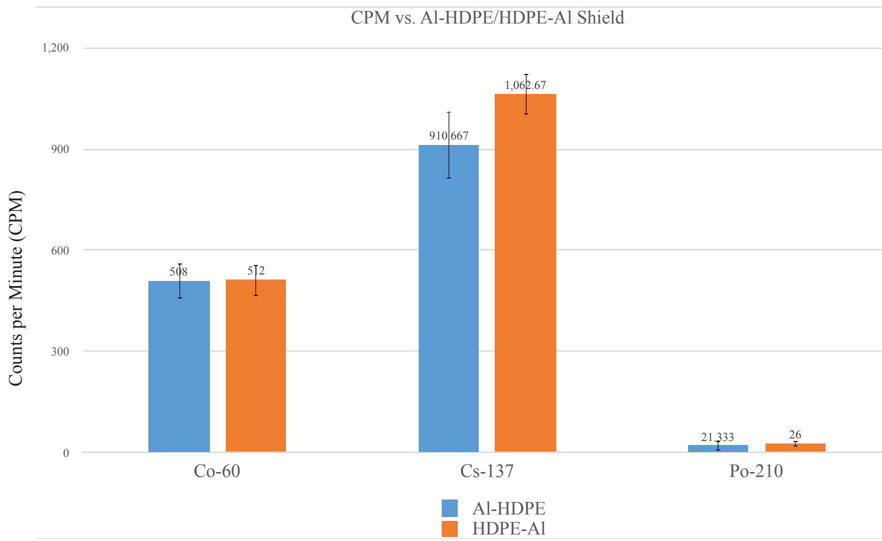

Figure 4: CPM (± S.E.) comparison between Al-HDPE and HDPE-Al shield orientations for Co-60, Cs-137 and Po-210. Only Cs-137 produced a difference (p < 0.05) in shield effectiveness based on orientation.

Urine-Water Shielding

No difference was found between urine and water shields of the same thickness (Fig. 5 - p < 0.05).

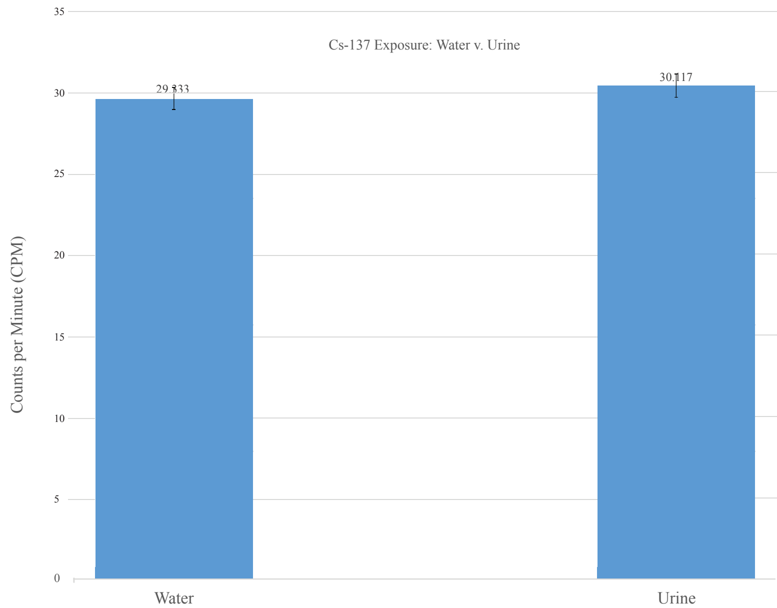

Figure 5: CPM (± S.E.) comparison between water and urine shields (t = 0.87 in.). No difference (p < 0.05) found between CPM on leeward side of shields.

Hydrated-Dehydrated Feces Shielding

No difference was found between hydrated and dehydrated feces shields of the same thickness (Fig. 6 - p < 0.05).

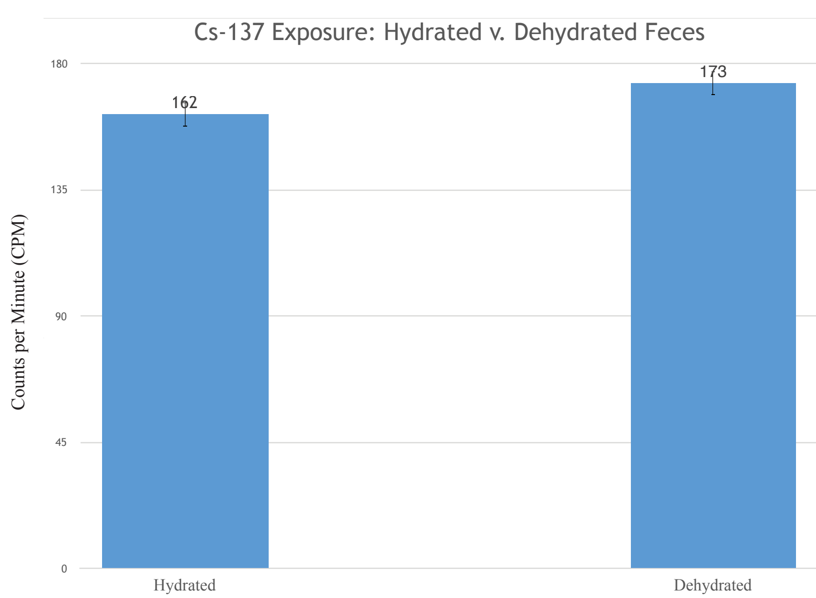

Figure 6: CPM (± S.E.) comparison between hydrated and dehydrated feces shields (t = 0.87 in.). No difference (p < 0.05) found between CPM on leeward side of shields.

There was a 33% decrease in mass from hydrated to dehydrated feces **(Table 1)**.

Hydrated (g)	Dehydrated (g)	Difference (%)
14.6	9.75	33

Table 1: Mass of hydrated and dehydrated feces used for shielding

Discussion

This work encompassed the validation of a radioisotope surrogate to simulate SPE particles through comparative testing of radiation attenuation amongst both urine vs. water and hydrated vs. dehydrated feces shields.

The data mirroring behavior predicted in OLTARIS (Slaba et al., 2011) supports the use of Cs-137 as a stand-in for SPE particles during the subsequent shielding experiments. The lack of difference in shielding effectiveness found between urine and water suggests that urine carries more value in water reclamation operations than in radiation shielding. Given the corrosive nature of brine produced during water reclamation (Jr. et al., n.d.), it is unlikely that the solid components of urine would yield a worthwhile return in the form of radiation shielding.

The lack of difference in shielding effectiveness between hydrated and dehydrated feces suggests that the hydration level of feces should not be considered a significant factor in radiation shielding operations. This result may influence decisions encompassed by the holistic nature of space travel: the moisture contained in feces could be reclaimed and the remaining solid mass integrated into radiation shields, without fear of detrimental influences on shielding effectiveness.

Conclusion

There was no difference in radiation attenuation effectiveness between equal thickness shields of urine vs. water and hydrated vs. dehydrated feces. These results suggest that the reclamation of water from human biowaste does not detract from the waste's potential as a radiation shield.

While Cs-137 was validated as a small scale SPE surrogate, the conclusions reached in this paper may be strengthened by experiments involving higher power sources with greater particle specificity, such as HIMAC (Marc M. Cohen, n.d.).

References

Encyclopedia Britannica. (2002). Feces.

Horneck, G., Facius, R., Reichert, M., Rettberg, P., Seboldt, W., Manzey, D., Gerzer, R. (2006). Humex, a study on the survivability and adaptation of humans to long-duration exploratory missions, part ii: Missions to mars. *Advances in Space Research*, 38(4), 752 -759. Retrieved from http://www.sciencedirect.com/science/article/pii/S0273117705008653 (Mercury, Mars and Saturn) doi: http://dx.doi.org/10.1016/j.asr.2005.06.072

Jr., D. E. L., Carter, D. L., & Higbie, S. (n.d.). Development of an advanced recycle filter tank assembly for the iss urine processor assembly.

Langford, M. (n.d.). Why is space radiation an important concern for human spaceflight?Retrieved from https://srag.jsc.nasa.gov/spaceradiation/why/why.cfmz

Miller, J., Cohen, M. M., Parodi, J. (n.d.). Water walls radiation shielding: Preliminary beam testing of ersatz solid waste simulant.

Rose, C., Parker, A., Jefferson, B., & Cartmell, E. (2015, Sep). The characterization of feces and urine: A review of the literature to inform advanced treatment technology. *Critical Reviews in Environmental Science Technology*, 45(17), 1827–1879.

Simon, M. A., Clowdsley, M., & Walker, S. (n.d.). Habitat design considerations for imple- menting solar particle event radiation protection.

Slaba, T. C., McMullenb, A. M., Thibeaulta, S. A., Sandridgea, C. A., Clowdsleya, M. S., & Blattniga, S. R. (2011). Oltaris: An efficient web-based tool for analyzing materials exposed to space radiation.

About the Author

Noah Falck is a Mustang alumnus who graduated in Winter 2017 with a B.S. in Aerospace Engineering (Astronautics) and minors in Biology and Military Science. If he is not working on the Jeep or cooking, he can be found out running trails and spending time with our equine friends. He believes that exploration is at the core of what it means to be a human and aims to study Bioastronautics after service in the Army.

Acknowledgements

I would like to thank Dr. Abercromby for providing vacuum chamber facilities at the Space Environments Laboratory and the Aerospace Engineering Department for funding to acquire the radioisotopes and data collection hardware. Additionally, Dr. Howes of the Biological Sciences Department aided in hardware supply and helped train me in the process of experimental design and biological best practices.