

Space Radiation: Impact on Astronauts and Preventive Measures

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As human space exploration extends beyond low Earth orbit (LEO), astronauts are increasingly exposed to harmful space radiation, which poses a significant threat to their health and mission success. Unlike the Earth's surface, where the atmosphere and magnetic field offer natural protection, space travelers encounter high-energy particles from galactic cosmic rays (GCRs), solar particle events (SPEs), and trapped radiation belts. These particles can cause severe biological damage, including DNA mutations, cancer, cognitive deficits, cardiovascular issues, and ocular degeneration. This review explores the origin and types of space radiation, the associated physiological and genetic risks to astronauts, and evaluates current mitigation strategies such as spacecraft shielding, pharmacological interventions, and mission planning. Additionally, it highlights future preventive measures under development, including active shielding, genomic tools, and advanced materials. Understanding and addressing space radiation risks are vital for the safety and sustainability of long-duration missions to the Moon, Mars, and beyond.

1. INTRODUCTION

As humanity prepares to venture beyond the relative safety of low Earth orbit, the increased exposure to space radiation becomes a formidable challenge for long-term space missions. Unlike the Earth's atmosphere, which shields its inhabitants from various forms of cosmic radiation, space environments present a myriad of radiation sources, such as galactic cosmic rays and solar particle events, that pose significant health risks to astronauts. These risks include potentially severe biological effects, such as DNA damage, increased cancer probabilities, and cognitive impairments, necessitating the development of effective countermeasures. Understanding the radiation environments encountered in space is crucial for designing and implementing protective strategies that can safeguard crew members on extended missions. Consequently, addressing these concerns through an integrated approach to radiation protection is imperative for ensuring the safety and health of astronauts as they explore deeper into the cosmos. Understanding and addressing space radiation risks are vital for the safety and sustainability of long-duration missions to the Moon, Mars, and beyond. Continued interdisciplinary research is essential to develop effective countermeasures and ensure long-term human presence in space.

A. Sources and Types of Space Radiation

Understanding the distinct sources and types of space radiation is essential for assessing their potential hazards to astronauts. Galactic Cosmic Rays (GCRs) are high-energy particles, predom-

inantly protons and helium nuclei, that originate from outside our solar system and have the capacity to inflict complex biological damage due to their ability to penetrate deep into cellular structures. In contrast, Solar Particle Events (SPEs), which are sporadic and unpredictable bursts, primarily occur during solar flares, releasing a surge of energetic protons that pose immediate risks to astronauts during extravehicular activities. Meanwhile, the trapped radiation belts surrounding Earth, notably the Van Allen Belts, consist of protons and electrons that predominantly impact missions within low Earth orbit [1]. Each of these radiation types presents unique challenges that necessitate tailored protective measures, reinforcing the critical need for comprehensive strategies in advanced space mission planning.

B. Biological Impact of Space Radiation

Space radiation poses significant biological challenges by inflicting harm on astronauts' DNA, which can lead to mutagenesis and carcinogenesis. High-LET radiation, such as that from galactic cosmic rays, is particularly damaging because it can cause double-strand breaks in DNA that are complex to repair, thereby elevating cancer risks [2]. Moreover, exposure to space radiation has profound implications for the central nervous system, potentially inducing neuroinflammation and cognitive impairments. Intriguingly, some research suggests that under certain conditions, space radiation could enhance cognitive abilities, though this remains an area under investigation [3]. Additionally, long-term exposure is associated with increased risks of

developing cardiovascular diseases and cataracts, as the radiation accelerates processes like atherosclerosis and ocular lens damage, further emphasizing the need for effective protective measures in space exploration.

C. Current Preventive Measures

To mitigate the adverse effects of space radiation on astronauts, several current preventive measures have been implemented. Physical shielding remains a primary line of defense, utilizing materials such as polyethylene and hydrogen-rich compounds that effectively absorb and deflect harmful radiation. These materials are strategically integrated into spacecraft design, providing passive protection during missions [4]. Complementing these structural defenses, pharmacological agents, including antioxidants and radioprotective drugs, are being investigated for their potential to protect cellular integrity against ionizing radiation [1]. Additionally, advanced mission planning and monitoring practices are increasingly critical; through radiation forecasting and exposure scheduling, astronauts' time spent in high-risk scenarios is minimized, further safeguarding their health during extravehicular activities.

D. Emerging and Future Strategies

In the quest for enhanced radiation protection, innovative strategies are focusing on integrating biological and technological approaches. Among these, biological countermeasures like genetic engineering and probiotic therapies show promise in improving DNA repair mechanisms, potentially mitigating the risks posed by high-linear energy transfer (LET) radiation. Concurrently, active shielding techniques, such as electromagnetic and plasma-based systems, are being investigated as plausible solutions for diverting harmful particles away from spacecraft. Furthermore, emerging developments in spacecraft architecture prioritize materials that are not only adept at self-repair but also capable of adapting to radiation exposure, thus enhancing overall structural resilience [4]. Wearable protection technologies are also advancing, with prototypes focusing on radiation-shielded suits and integrated sensors to provide astronauts with real-time exposure assessments, ensuring that the protection measures remain as dynamic as the ever-changing space environment.

Additionally, insights from NASA's Human Research Program and the NASA Twins Study provide valuable data on the effects of space radiation and the potential for recovery. The Twins Study involved comprehensive monitoring of identical twin astronauts, with one in space and the other on Earth, allowing for a unique examination of the consequences of radiation exposure in space [5]. Findings indicated significant genetic and physiological changes, such as alterations in DNA repair mechanisms, which underscore the complexity of biological responses to space radiation. Moreover, the study identified differences in immune system function and telomere length dynamics, shedding light on the multifaceted impact of space travel on human health [6]. These case studies highlight the need for continued research to develop effective countermeasures, ensuring the safety of astronauts as missions venture deeper into space, and emphasizing the importance of a multifaceted approach to radiation protection.

3. CONCLUSION

The advancement of deep-space missions requires a comprehensive approach that efficiently integrates technological innovations with biological insights. By unifying disciplines such as materials science, pharmacology, and genetic research, we can develop multifaceted protective strategies against space radiation. These strategies are paramount in addressing the myriad health risks astronauts face, including potential DNA damage, neurocognitive effects, and cardiovascular issues. Aligning technological methods like active shielding and adaptive spacecraft materials with biological countermeasures enables a robust defense against radiation hazards. As humanity ventures further into space, adopting an interdisciplinary approach is crucial to ensuring the long-term health and safety of astronauts, paving the way for successful exploration of our solar system and beyond.

REFERENCES

1. V. Wotring, *Spaceflight pharmacology. In Principles of clinical medicine for space flight* (Springer, New York, 2020).
2. Z. Guo, G. Zhou, and W. Hu, "Carcinogenesis induced by space radiation: A systematic review," *Neoplasia* **32** (2022).
3. V. S. Kokhan and M. I. Dobynde, "The effects of galactic cosmic rays on the central nervous system: From negative to unexpectedly positive effects that astronauts may encounter," *Biology* **12**, 400–400 (2023).
4. C. A. Montesinos, R. Khalid, O. Cristea, J. S. Greenberger, M. W. Epperly, J. A. Lemon, D. R. Boreham, D. Popov, G. Gorthi, N. Ramkumar, and J. A. Jones, "Space radiation protection countermeasures in microgravity and planetary exploration," *Life* **11**, 829–829 (2021).
5. Z. Dai, X. Lei, C. Yang, L. Zhao, L. Lu, and Y. Li, "Systematic biomedical research of the NASA Twins Study facilitates the hazard risk assessment of long-term spaceflight missions," *Protein & Cell* **10**, 628–630 (2019).
6. F. E. Garrett-Bakelman, M. Darshi, S. J. Green, R. C. Gur, L. Lin, B. R. Macias, M. J. McKenna, C. Meydan, T. Mishra, J. Nasrini, and B. D. Piening, "The NASA Twins Study: A multidimensional analysis of a year-long human spaceflight," *Science* **364** (2019).