

# EFFECT OF COSMIC RADIATION TO PROPERTIES OF NANOPARTICLES: REVIEW ARTICLE

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## ABSTRACT

Cosmic radiation which is made up of high energy protons, heavy ions, and secondary particles, presents and having extreme environment capability of altering properties in nanomaterials. When nanoparticles are exposed to such radiation in space or high altitude conditions, they undergo structural, chemical, and electronic transformations that deviate significantly from their behavior under terrestrial conditions. Ionizing radiation can generate defects, alter surface morphology (like that of ion implantation and nanostructuring) and induce amorphization or phase transitions. This will lead alteration in so many physical and chemical properties like that conductivity, magnetism, and catalytic activity. Quantum confinement effects in nanoparticles may amplify these changes, as the high surface-to-volume ratio renders them exceptionally sensitive to ionization and displacement damage. This interaction between cosmic energy and matter at the nanoscale opens pathways for novel material properties and resilience, while also posing challenges for nanotechnology applications in aerospace, satellite systems, and space exploration. Understanding and harnessing these effects could lead to the design of radiation-hardened nanodevices and materials tailored for the cosmos.

**KEYWORDS:** *Cosmos, Quantum Confinement Effect, Nanoparticles*

## Introduction

Cosmic radiation refers to high energy particles originating from outer space that continuously bombard Earth and other celestial bodies. Cosmic radiation could be classified into three main sources as follows.

Galactic Cosmic Rays (GCRs):

Originating outside the solar system, likely from supernovae explosions and other high-energy astrophysical events in Milky Way, GCRs are composed primarily of high-energy protons (~85%), alpha particles (~14%), and a small fraction of heavier nuclei known as HZE (High-Z and Energy) particles. Electrons are also found in extreme small fractional amount. These particles can possess energies exceeding  $10^{18}$  eV and represent a major radiation hazard in deep-space missions.

Solar Particle Events (SPEs):

Emitted during solar flares and coronal mass ejections, SPEs consist mostly of high-energy protons, along with electrons and heavier ions. While typically lower in energy than GCRs, their intensity can spike dramatically during solar storms, posing acute radiation risks to astronauts and electronic systems.

## Trapped Radiation Belts:

These belts surround Earth and trap charged particles from the solar wind and cosmic rays within the planet's magnetic field. They contain mostly electrons and protons and vary in intensity depending on altitude and geomagnetic activity.

The intensity of cosmic radiation depends on several factors such as altitude, shielding, geomagnetic latitude, and solar activity. For example, astronauts in low Earth orbit (LEO) experience radiation doses far above Earth's surface levels, while interplanetary missions—such as to the Moon or Mars—encounter much higher and more variable radiation fields, especially outside the protective influence of Earth's magnetosphere.

Understanding the nature of cosmic radiation is a fundamental aspect to predicting and in order to make some justification its effects on nanoparticles, which may respond differently to various types and energies of incident particles due to their scale and surface dominant properties.

The interaction between cosmic radiation and nanomaterials has emerged as a critical area of study, particularly as humanity ventures deeper into space and relies increasingly on nanoscale technologies for both terrestrial and extraterrestrial applications. Nanoparticles—owing to their high surface area-to-volume ratio, quantum confinement effects, and unique physicochemical properties, thermal properties, electrical properties, magnetic properties exhibit their behaviour under radiation that diverges significantly from bulk materials. This makes them both highly sensitive and uniquely responsive to cosmic radiation environments.

Understanding these interactions is essential for several reasons. First, in the context of space exploration and satellite technology, nanoparticles are increasingly integrated into systems for electronics, coatings, sensors, and energy storage. These components must withstand extreme conditions, including continuous exposure to high-energy particles originating from solar flares, galactic cosmic rays, and trapped radiation belts. Radiation-induced changes at the nanoscale can lead to degradation, altered performance, or unexpected failure, posing significant risks to mission success.

Second, nanoparticles themselves may serve as functional materials in radiation shielding, medical applications (e.g., radioprotective agents for astronauts), and environmental sensing. A thorough understanding of how cosmic radiation modifies their properties can lead to more robust material design and predictive performance models under high-radiation conditions.

Third, the study of cosmic radiation effects on nanoparticles provides insights into broader physical phenomena, including defect dynamics, radiation chemistry, and particle-matter interactions at the nanoscale. These findings have implications for fields beyond space science, such as nuclear medicine, particle physics, and materials science.

Finally, investigating these effects also supports fundamental research in astrochemistry and planetary science, helping to explain the behavior of cosmic dust, interstellar nanoparticles, and the stability of prebiotic molecules exposed to radiation in the early solar system.

Thus, the relevance of studying nanoparticle behavior under cosmic radiation is both practical and scientific, underpinning future advancements in space technology, radiation protection, and the broader understanding of matter in extreme environments.

Despite progress, there are still significant gaps:

- Limited systematic studies across different nanoparticle types and sizes
- Inadequate data on combined space factors (radiation + microgravity + temperature extremes)
- Few long-duration exposure datasets

As a result, the field is ripe for exploration, especially as nanoscale materials become integral to space-based sensors, electronics, and biomedical devices.

## Proposed Experimental:

### Standardization of Experimental Conditions for Studying Cosmological Effects on Nanoparticles:

One of the major challenges in understanding the influence of cosmic radiation on nanoparticles lies in the lack of standardized experimental protocols. Unlike well-established radiation testing procedures for bulk materials and electronics, nanoparticle studies often vary widely in terms of radiation sources, dosimetry, environmental controls, and characterization techniques.

#### 1. Variation in Radiation Sources

Studies simulate cosmic radiation using a range of particle accelerators or ion beam facilities. However, the types of ions used (e.g., protons, helium, heavy ions), energy levels, and fluences differ significantly, making cross-study comparisons difficult. Moreover, space radiation consists of a complex, mixed field of particles, which is not fully replicated in most laboratory environments.

#### 2. Dose and Dose Rate Discrepancies

Nanoparticle experiments are often conducted with accelerated, high-dose exposures to simulate long-term effects in a shorter time. However, the **dose rate** can influence damage mechanisms, and such accelerated conditions may not accurately reflect the slow, cumulative effects experienced in space. A standard protocol for dose scaling is needed.

#### 3. Environmental Factors

In space, nanoparticles are exposed not just to radiation but to vacuum, extreme temperatures, and microgravity. Most lab experiments neglect these combined effects, leading to oversimplified conclusions. Including environmental simulators or standardizing co-exposure conditions would enhance relevance.

#### 4. Nanoparticle Variability

Different studies use nanoparticles with varying:

- Sizes
- Shapes (spheres, rods, sheets)
- Surface chemistries and coatings
- Crystalline and amorphous states

Without standardized reporting on these parameters, it becomes difficult to attribute observed radiation effects to specific properties. A database of well-characterized, benchmark nanoparticle types for radiation studies would improve reproducibility and clarity.

#### 5. Characterization Protocols

Post-irradiation analysis often employs a variety of techniques: TEM, XRD, Raman spectroscopy, and others. However, there's a need for:

- Standardized time points for analysis post exposure
- Guidelines on damage quantification, such as defect density or functional loss
- Consistency in reporting results, including error margins and control comparisons

## 6. Interdisciplinary Gaps

Cosmic radiation studies on nanoparticles span across space science, physics, nanotechnology, and biology. Lack of common language and standards across these disciplines slows progress. Collaborative initiatives and shared databases could help bridge these gaps.

### The Way Forward

Efforts to standardize testing protocols, including establishing reference nanoparticle materials, defining standard radiation spectra, and adopting unified reporting formats, are critical for meaningful comparisons and cumulative scientific progress. This will be essential not only for advancing basic understanding but also for qualifying nanomaterials for aerospace, defense, and biomedical applications under radiation-rich conditions.

### Long Term Exposure Studies of Cosmic Effects on Nanoparticles

Despite increasing interest in radiation effects at the nanoscale, long-term exposure studies on nanoparticles under cosmic radiation conditions remain scarce and are one of the most critical gaps in current research. Most existing investigations rely on short-duration, high-dose laboratory simulations, which do not fully capture the cumulative, slow degradation that occurs in real space environments.

#### 1. Need for Prolonged, Realistic Exposure

In space, nanoparticles are exposed to low-flux but highly energetic particles over extended periods—weeks, months, or even years. These conditions can lead to:

- Gradual defect accumulation
- Amorphization or phase transformations
- Slow oxidation, coalescence, or morphological evolution Such long-term effects can drastically alter a nanoparticle's physical, chemical, or functional performance—often in ways not predicted by short-term tests.

#### 2. Space-Based Experiments

There have been some efforts to conduct long-term material exposure experiments:

- Platforms like MISSE (Materials International Space Station Experiment) on the ISS have tested bulk materials and coatings, but nanoparticle-specific data is limited.
- Newer missions using CubeSats or deployable testbeds are beginning to explore nanoscale materials, but systematic, controlled exposure studies are still lacking.

#### 3. Simulation vs. Reality

While ion beam accelerators and plasma sources can simulate aspects of cosmic radiation, they typically operate under intensified doses and short durations. This may:

- Induce nonlinear damage pathways
- Miss slow-acting synergistic effects, such as those between radiation and thermal cycling or vacuum exposure
- Overlook time-dependent recovery or annealing effects, particularly important in self-healing or adaptive nanomaterials

#### 4. Importance for Space Applications

Long-term performance is vital for applications in:

- Deep space missions (e.g., Moon, Mars, interplanetary travel)
- Long-life satellites and telescopes
- Radiation-hardened nanoelectronics
- Biological shielding and therapeutic nanoparticles in space medicine

In such missions, nanoparticle-based components must function reliably for years, making it essential to predict and understand their behavior under prolonged cosmic radiation.

#### 5. Future Directions

To close this research gap, the following steps are recommended:

- Develop long-duration test protocols that include cumulative dose modeling and real-time monitoring
- Launch dedicated nanoparticle testbeds aboard space stations or deep-space probes
- Combine real exposure data with multiscale modeling to simulate decades-long effects
- Encourage international collaboration between space agencies, nanoscience labs, and radiation physics centers

#### Conclusion

Long-term exposure studies are indispensable for transitioning nanomaterials from theoretical promise to real-world use in cosmic environments. Without this data, risks associated with degradation, failure, or unintended property shifts in nanoparticle-based systems remain high posing challenges to both mission success and human safety.

#### References

1. International Conference on Radiation Safety: Improving Radiation Protection in Practice. Extended Abstracts (Virtual Event), pp 80 -81, 2021.
2. Babu B, Pawar S, Mittal A, Kolanthai E, Neal CJ, Coathup M, Seal S. Nanotechnology enabled radioprotectants to reduce space radiation-induced reactive oxidative species. *Wiley Interdiscip Rev Nanomed Nanobiotechnol.* 2023 Sep-Oct;15(5)
3. *Journal of Instrumentation*, IOP Publishing, Vol 19, A. Nikrah, P. Taherparvar and A. Sadremomtaz 17 December 2024.
4. Abd El-Hameed, A. M. (2022) 'Radiation effects on composite materials used in space systems: a review', *NRIAG Journal of Astronomy and Geophysics*, 11(1), pp. 313–324. doi: 10.1080/20909977.2022.2079902.