IRA-International Journal of Applied Sciences
ISSN 2455-4499; Vol.21, Issue 03 (Q3. 2026)
Pg. no. 102-118.
IRA Academico Research

Extending The Shelf Life of Drugs for Long-Duration Space Flight for Commercial Possibilities- A Qualitative Review

Gurpreet Kaur Chhabra[1#], **Akshita Garg**[2]
[1]Associate Professor, MERI College, New Delhi, India.
[2]Student MBA Sem 4, MERI College, New Delhi, India.

[#]corresponding author
Type of Work: Peer Reviewed.
DOI: https://dx.doi.org/10.21013/jas.v21.n3.p1

Review history: Submitted: July 09, 2026; Revised: July 29, 2026; Accepted: August 12, 2026.

How to cite this paper:
Chhabra, G. K., & Garg, A. (2026). Extending The Shelf Life of Drugs for Long-Duration Space Flight for Commercial Possibilities- A Qualitative Review. *IRA-International Journal of Applied Sciences* (ISSN 2455-4499), 21(3), 102-118. https://dx.doi.org/10.21013/jas.v21.n3.p1

Gurpreet Kaur Chhabra / 0009-0002-0846-127x

ABSTRACT

The prevalence of polypharmacy, particularly among older persons and people with chronic diseases, has raised the dangers associated with drug interactions, medication noncompliance, and complex dosing. Single-dose combination tablets, sometimes known as polypills, are a promising option to streamline treatment schedules while remaining effective. This study investigates the formulation, safety, and technological advances involved in producing single-dose tablets containing numerous active pharmacological ingredients without compromising drug stability or increasing the risk of adverse interactions.

The study focuses on the physical and chemical obstacles of mixing medicines with varying solubility, release patterns, and metabolism routes. It focuses on identifying and mitigating potential medication interactions both during the formulation process and in the body. Multilayer tablet design, compartmentalized drug delivery systems, and controlled-release coatings are investigated for their potential to separate incompatible substances while allowing for synchronized or sequential drug release.

Furthermore, the study investigates how upcoming technologies such as 3D printing and nanotechnology aid in the optimal spatial delivery of numerous compounds within a single tablet. This enables a personalized drug delivery mechanism and improves absorption. The use of computer modeling and artificial intelligence to forecast interaction risk and optimize formulation procedures prior to manufacture is also investigated.

In terms of regulatory and clinical aspects, emphasis is focused on the importance of conducting rigorous testing to verify the safety, efficiency, and dependability of multi-drug formulations. Furthermore, the report mentions patient-centered design, which can be aided by employing a single pill rather than multiple medications because it simplifies regimen administration and increases compliance.

The findings of this research demonstrate that, despite the challenges of compatibility and stability, pharmaceutical science and technology have made significant progress, making it possible to design an efficient and safe formulation. This will change the practice and make life easier for both doctors and patients.

Keywords: Space medicine, pharmaceutical stability, drug shelf life, microgravity, cosmic radiation, advanced packaging, long duration missions, astronaut healthcare.

1. Introduction

Human space exploration is rapidly progressing beyond short orbital missions toward long-term habitation in space, including planned missions to the Moon and Mars. These missions may continue for several months or years, making astronaut healthcare one of the most critical operational requirements. Since resupply from Earth is extremely limited during deep-space missions, astronauts must rely on medicines stored onboard for prolonged periods.

Unlike conditions on Earth, pharmaceuticals in space are exposed to unique environmental stresses. Microgravity, cosmic radiation, vibration during launch, fluctuating temperatures, and restricted storage capacity can alter the physical and chemical properties of medications. Such exposure may reduce drug potency, shorten shelf life, and increase the risk of treatment failure during missions.

Studies conducted on medications stored aboard the International Space Station (ISS) have shown that some pharmaceutical products lose effectiveness more quickly in space than under normal terrestrial conditions. Repackaging medications before launch has also been identified as a major factor contributing to instability because it exposes medicines to moisture, oxygen, and contamination.

Among all environmental challenges, radiation exposure remains one of the most serious concerns for pharmaceutical preservation in space. High-energy particles may damage active pharmaceutical ingredients and accelerate chemical degradation. Liquid formulations are considered especially vulnerable because microgravity can influence fluid behavior, solubility, and molecular stability. In comparison, solid dosage forms such as tablets and capsules generally demonstrate greater resistance to environmental stress.

To overcome these challenges, researchers and pharmaceutical companies are exploring several innovative solutions. These include advanced protective packaging systems, freeze-dried medicines, radiation-shielded storage containers, nanotechnology-based drug delivery methods, and 3D-printed pharmaceuticals that can potentially be manufactured during missions. Such technologies may improve medicine stability while reducing storage and transportation constraints.

Research on pharmaceutical preservation in space not only supports future human exploration missions but also offers practical benefits for healthcare systems on Earth. Improved drug stability technologies may assist remote regions, military operations, disaster-response environments, and areas with limited medical infrastructure.

2. Literature Review

Title of the Paper	Year	Author(s)	Factors/Variables Studied	Sample Size	Tools/Techniques Adopted	Findings
The Long-Term Stability of Solid-State Oral Pharmaceuticals Exposed to Simulated Intravehicular Space Radiation	2025	Ianik Plante, Vernie Daniels, Millennia Young, Ramona Gaza, Honglu Wu & John F. Reichard	Space-like radiation dose (GCR simulation), API content, impurities, dissolution	4 solid oral formulations	Simulated Galactic Cosmic Ray irradiation, long-term storage, potency testing	Radiation exposure at 1 Gy did not significantly accelerate deterioration in solid formulations. Packaging and storage conditions were found to be more important in determining stability.
Expiration Analysis of the International Space Station	2024	Thomas E. Diaz, Emma C. Ives, Diana I.	Terrestrial shelf-life of ISS medications	106 medications	Pharmacy record analysis and drug registry evaluation	Most ISS drugs had shelf lifetimes shorter than

Formulary for Exploration Mission Planning		Lazare & Daniel M. Buckland				those necessary for Mars missions, emphasizing the importance of shelf-life extension techniques.
The Effect of Long-Term Spaceflight on Drug Potency and the Risk of Medication Failure	2023	J. F. Reichard, S. E. Phelps, K. R. Lehnhardt, M. Young & B. D. Easter	Spaceflight exposure, storage time, repackaging, API degradation	36 drug products	HPLC potency assay, statistical modelling, longitudinal comparison	Drugs held in space degraded 1.5 times faster than those stored on Earth, with repackaging being the leading cause of potency loss.
Ground-Based Selected Ionizing Space Radiation Effects on Stability of APIs and Their Formulations	2022	Bhayani et al.	Radiation type, formulation state, API degradation	3 drug compounds in multiple formulations	Particle irradiation experiments, HPLC assay	Proton radiation caused severe deterioration, particularly in liquid formulations, whereas neutron exposure resulted in minor instability.
Impact of Space Environment on Stability of Medicines: Challenges and Prospects	2017	Priti Mehta & Dhara Bhayani	Space environmental factors, packaging strategies	NA	Space simulation analogues, probabilistic modeling	The study identified radiation, vacuum, and temperature variations as serious threats to pharmaceutical stability and recommended sophisticated protective packaging methods.

Chemical Potency and Degradation Products of Medications Stored Over 550 Earth Days at the International Space Station	2016	Wotring, V. E.	Drug potency after prolonged ISS storage	9 medications	HPLC analysis and USP potency evaluation	Several drugs maintained adequate efficacy after their expiration dates, indicating that some shelf-life extensions may be conceivable under controlled storage settings.
Evaluation of Physical and Chemical Changes in Pharmaceuticals Flown on Space Missions	2011	Brian Du, Vernie R. Daniels, Zalman Vaksman, Jason L. Boyd, Camille Crady & Lakshmi Putcha	Spaceflight effects on API content and dissolution	35 solid drug products	UHPLC, HPLC, USP dissolution testing	Space-flight drugs lost more potency than Earth-bound medications, with radiation exposure and repackaging recognized as major contributors.

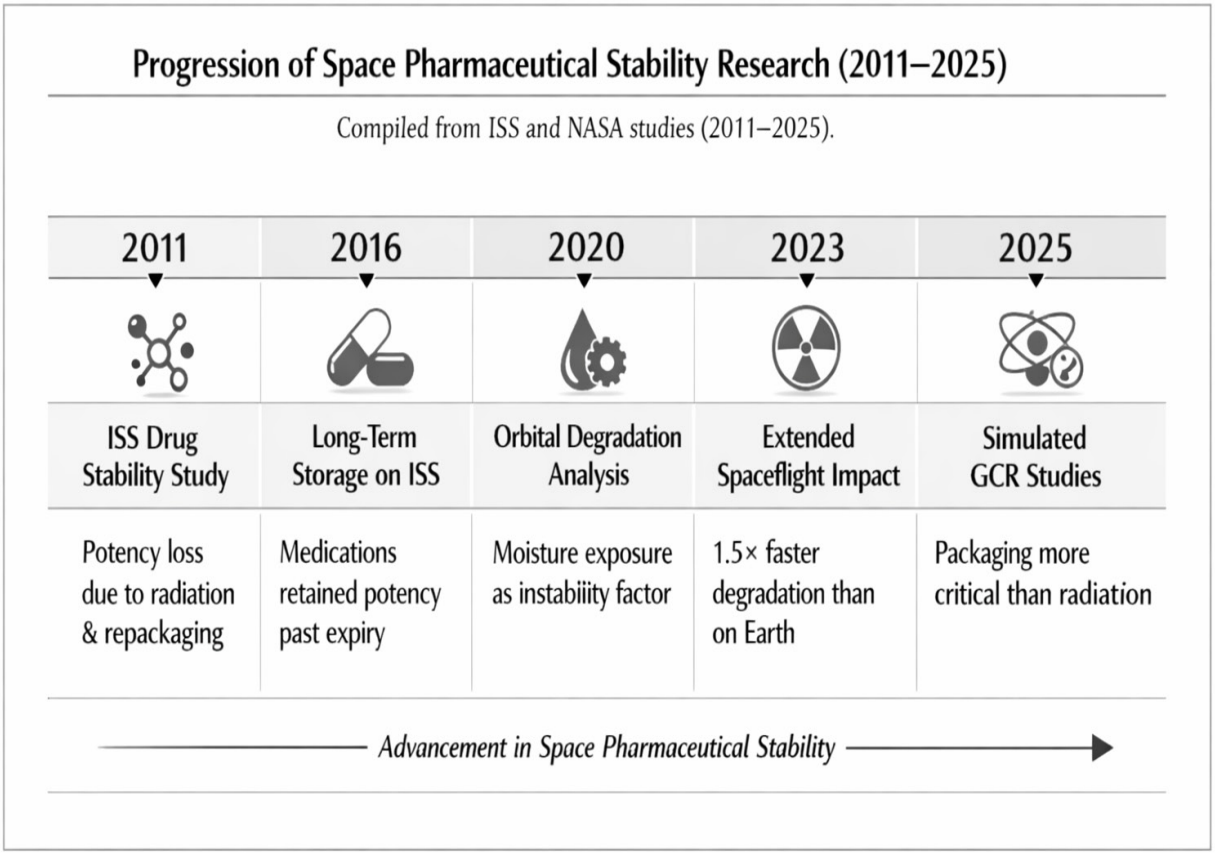

Figure 1: Chronological Progression of Space Pharmaceutical Stability Research (2011–2025)

3. Research Gap

3.1 There is a lack of study comparing the durability of medications in their original containers from manufacturers to repackaging into alternative containers developed expressly for space travel. What is the impact of repacking on drug deterioration in space?

3.2 There are insufficient investigations on the impact of formulations (liquids, capsules, or solids) in space.

3.3 There have been few studies on the impact of long-duration trips (such as to Mars).

3.4 Lack of investigation into logistics difficulties.

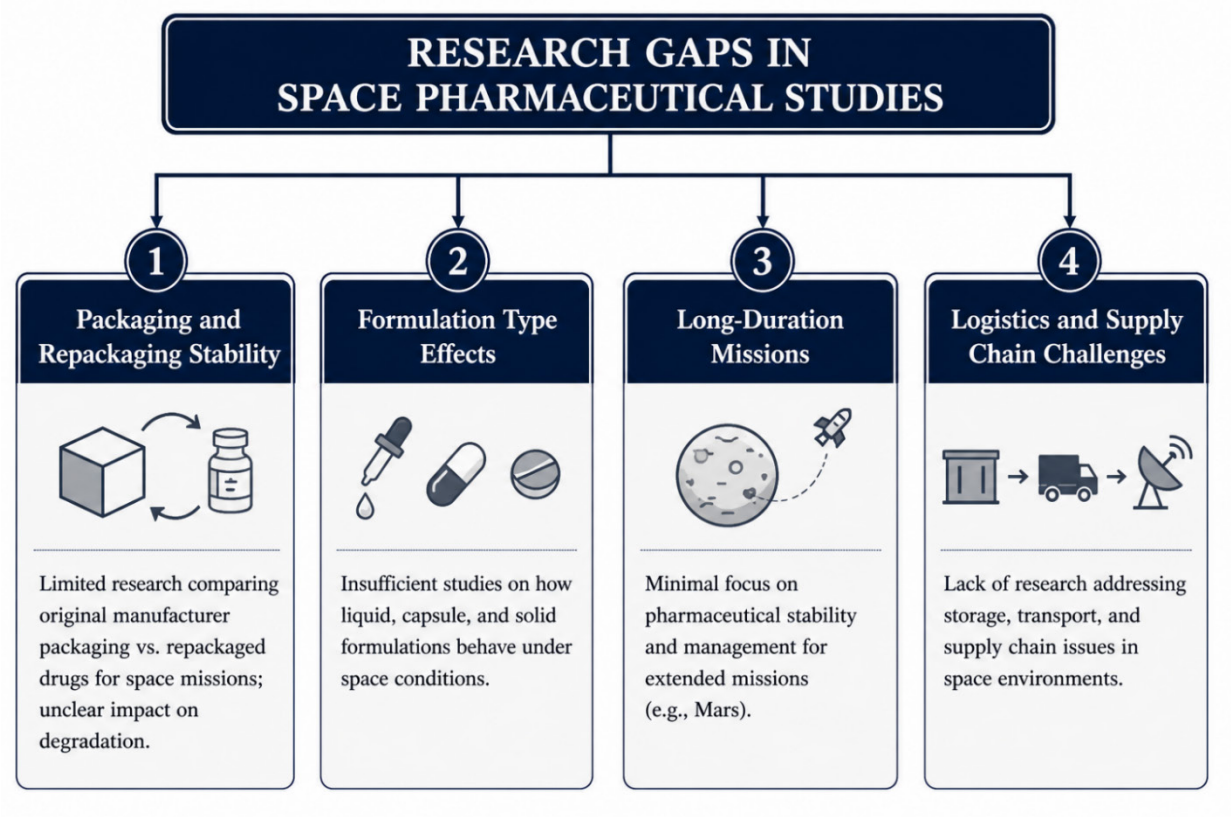

Figure 2: Research Gaps in Space Pharmaceutical Studies

4. Research Questions

4.1 How does drug packaging affect drug stability and degradation in the space environment?

4.2 How do medication formulations affect drug stability in space?

4.3 What obstacles may lengthy space flight, such as that involved in Mars mission, bring to drug stability?

4.4 How do logistics difficulties affect medicine storage in space missions?

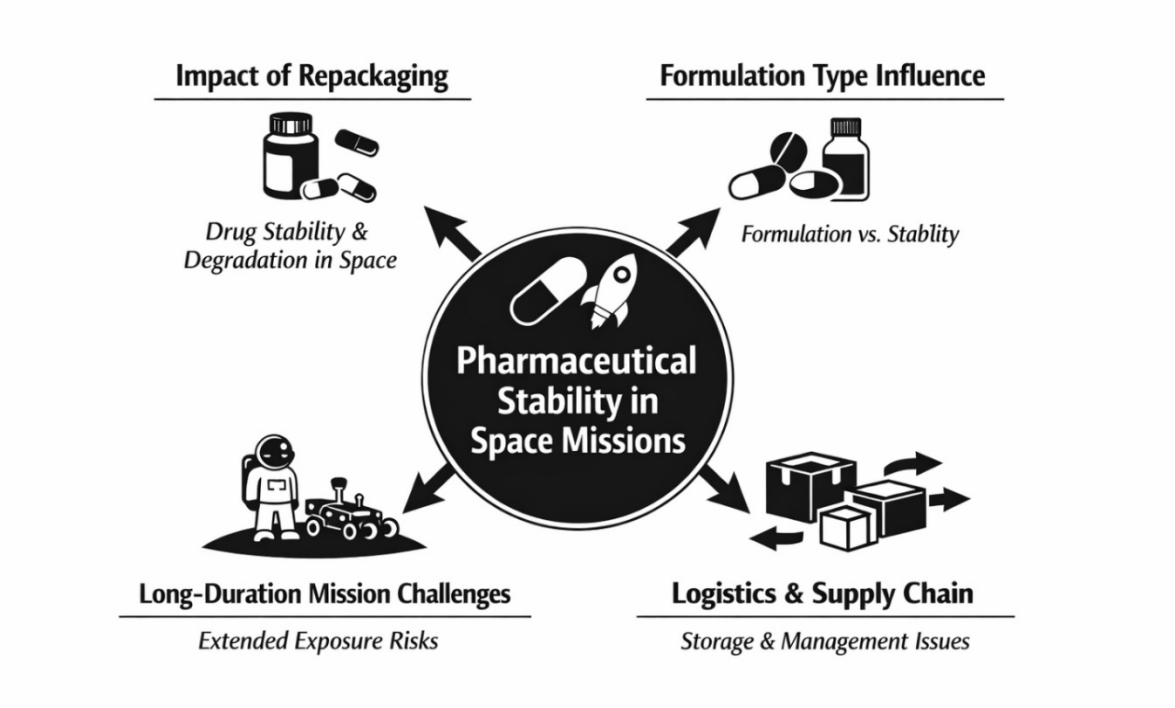

Figure 3: Research Questions in Space Pharmaceutical Studies

5. Research Methodology

5.1 Research Design

The study uses an exploratory research design to identify issues in pharmaceutical stability, storage, and management in space, especially for long-duration missions.

5.2 Nature of Data

- The research uses both primary and secondary data.
- Primary Data - 30%
- Secondary data - 70%.

5.3 Data Collection Methods

5.3.1 Primary Data

Primary data was acquired using:

Expert Opinions

Focus group interviews.

The following talks and expert views were collected during the conference:

“Leveraging Space to Speed Up Pharmaceutical Research in India”
held on **17 March 2026 at MERI College.**

Experts from the pharmaceutical, healthcare, and space research domains shared their perspectives regarding:

- pharmaceutical stability in space,
- storage and packaging challenges,
- logistics and supply chain concerns,
- future opportunities for India in space-based pharmaceutical research.

5.3.2 Secondary Data

Secondary data was collected from:

- research papers,
- journals,
- NASA and ISS studies,
- conference reports,
- pharmaceutical stability studies,
- articles related to space medicine and drug degradation.

5.4 Sample Size

The sample size for the study was 28 respondents/participants.

5.5 Sampling Unit / Sampling Framework

The sampling framework consisted of participants, experts, researchers, academicians, and professionals who attended the conference:

"Leveraging Space to Speed Up Pharmaceutical Research in India"
organized on **17 March 2026 at MERI College.**

5.6 Sampling Technique

The study used purposive sampling, as respondents were selected based on their knowledge, expertise, and involvement in pharmaceutical and space-related research discussions.

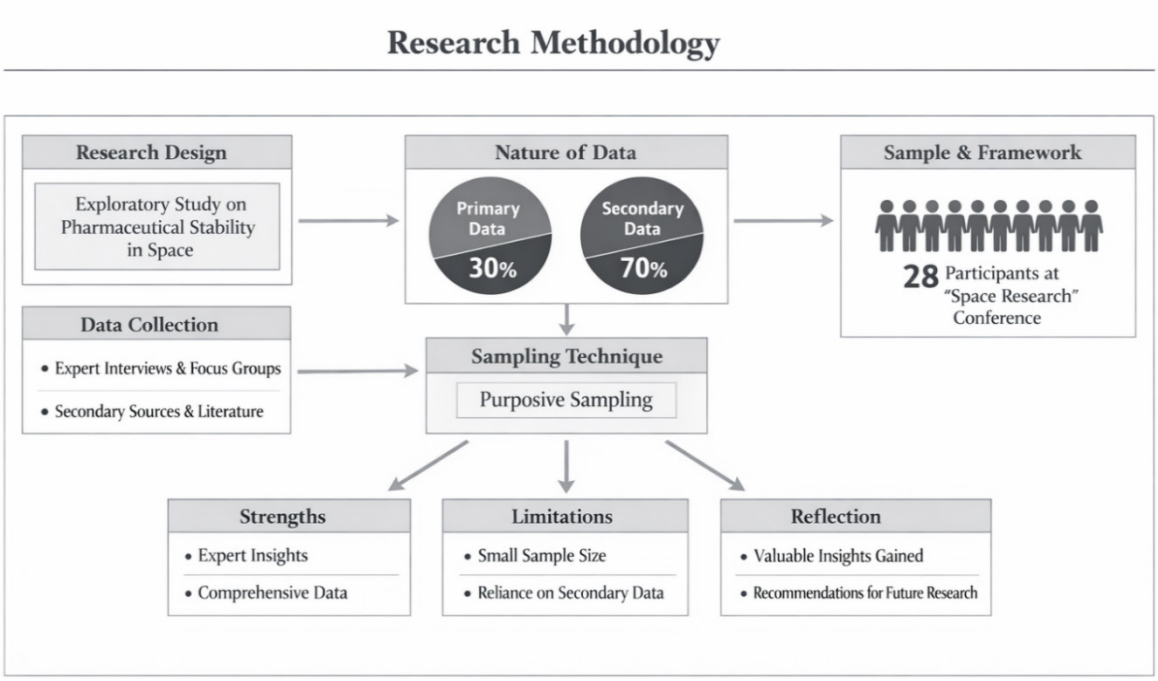

Figure 4: Research Methodology

6. Data Analysis

6.1 Expert Opinion Analysis

The expert opinion analysis was conducted based on insights shared by:

- **Lt Gen PJS Pannu**: Former Deputy Chief of Integrated defense Staff and strategic affairs expert with extensive experience in defense and space policy discussions.
- **Air Vice Marshal Dr. Anupam Agarwal**: Senior aerospace medicine specialist and expert in aviation healthcare, space medicine, and pharmaceutical challenges in extreme environments.
- **Dr. Neeta Kumar**: Healthcare and research professional focusing on astronaut health, medical systems, and healthcare innovation in space environments.

during the conference *"Leveraging Space to Speed Up Pharmaceutical Research in India"* held on 17 March 2026 at MERI College.

Observation Table – Expert Opinion

Expert	Major Observations	Key Themes Identified	Relevance to Research
Lt Gen PJS Pannu	Bharat Antariksh Station, Dark Labs, and microgravity-enabled drug crystallization were highlighted as key initiatives for quicker pharmaceutical innovation.	Orbital infrastructure, advanced medicine discovery, and strategic planning	Supports the need for long-term pharmaceutical research and space-based therapeutic development.
Air Vice Marshal Dr. Anupam Agarwal	Discussed drug degradation due to radiation, elevated CO_2, and microgravity. Emphasized advanced packaging and self-sustaining pharmaceutical systems.	Drug stability, storage issues, packaging innovation, and orbital manufacturing	Directly supports research into pharmaceutical degradation and repackaging difficulties in space.
Dr. Neeta Kumar	Focused on physiological and psychological health challenges, telemedicine, wearable technologies, and healthcare systems in space missions.	Space healthcare, astronaut health, AI monitoring, traditional medicine	Emphasizes the need for specific pharmacological systems for long-term missions.

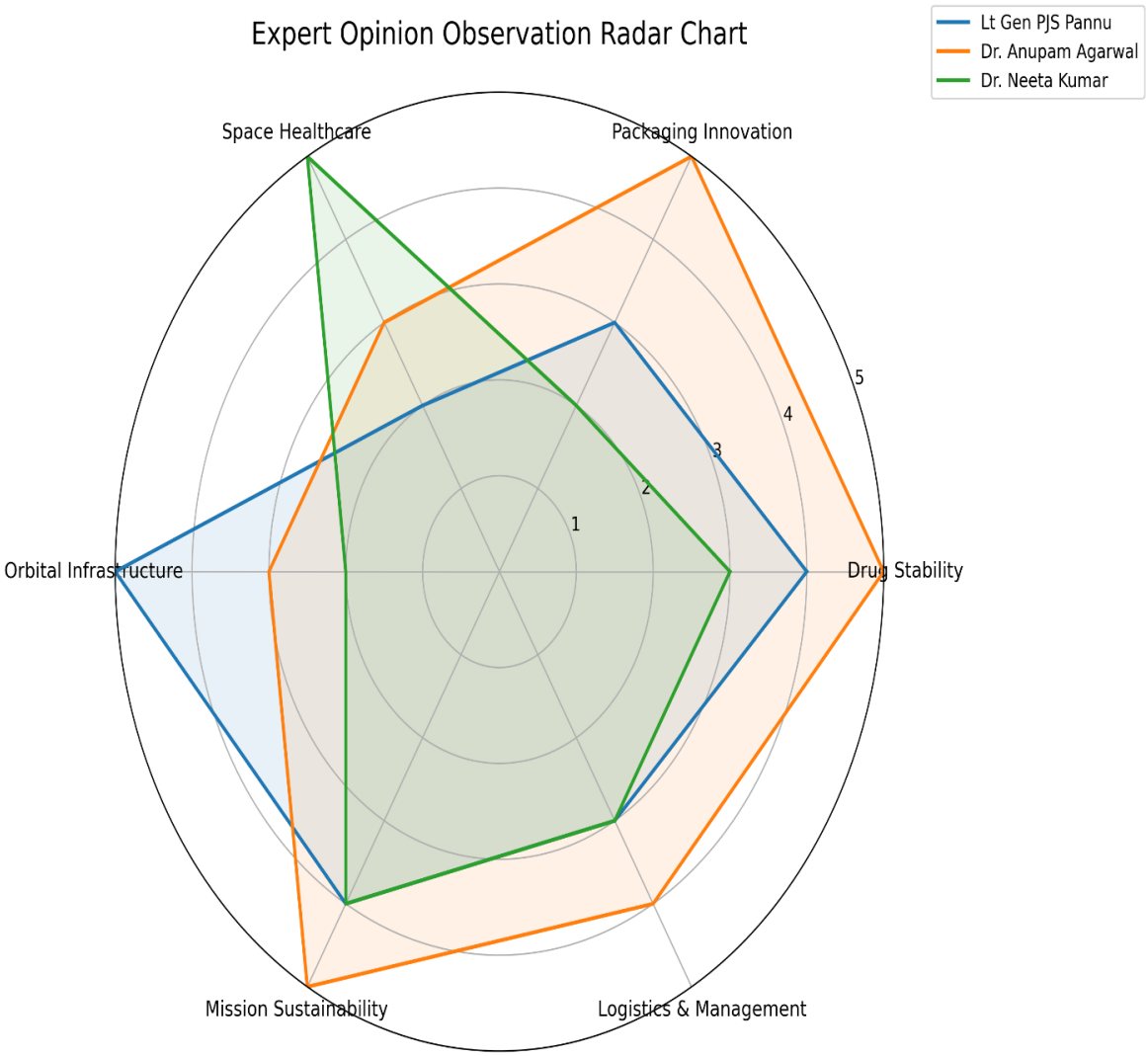

Figure 5: Expert Opinion Analysis

6.2 Focus Group Analysis

The focus group analysis included insights from:

- **Tejpaul Bhatia**: Industry expert associated with technology commercialization and innovation in emerging space and pharmaceutical sectors.
- **Dr. Anjan Sen:** Research professional specializing in space science, microgravity research, and pharmaceutical applications in orbital environments.
- **Dr. Sandeep Arora**: Medical and dermatological expert focusing on physiological changes and healthcare challenges during space missions.
- **Sree Supranayi**; Space logistics and transportation professional working on reusable systems and infrastructure for future space operations.
- **Dr. Parijat Pandey**: Research expert in nanotechnology and advanced drug delivery systems with focus on pharmaceutical innovation for space applications.

Observation Table – Focus Group Discussion

Participant/Group	Major Observations	Key Themes Identified	Relevance to Research
Tejpaul Bhatia	Emphasized commercialization of space pharma and importance of private sector participation.	Commercialization, industrial application, investment challenges	Highlights logistical and scalability challenges in space pharma.
Dr. Anjan Sen	Discussed microgravity benefits in protein crystallization and accelerated drug discovery.	Microgravity research, precision drug design	Supports research on formulation and pharmaceutical innovation.
Dr. Sandeep Arora	Highlighted skin-related physiological changes and need for specialized dermatological products in space.	Human health challenges, specialized pharmaceutical solutions	Demonstrates need for space-specific medicines and formulations.
Sree Supranayi	Focused on reusable space logistics systems and rapid transportation of pharmaceutical samples.	Space logistics, transportation systems, infrastructure	Directly linked to research gap on logistical challenges in space missions.
Dr. Parijat Pandey	Discussed nanotechnology, nano-encapsulation, and advanced drug delivery systems.	Drug stability, targeted delivery, nano-packaging	Supports research on advanced pharmaceutical packaging and stability enhancement.

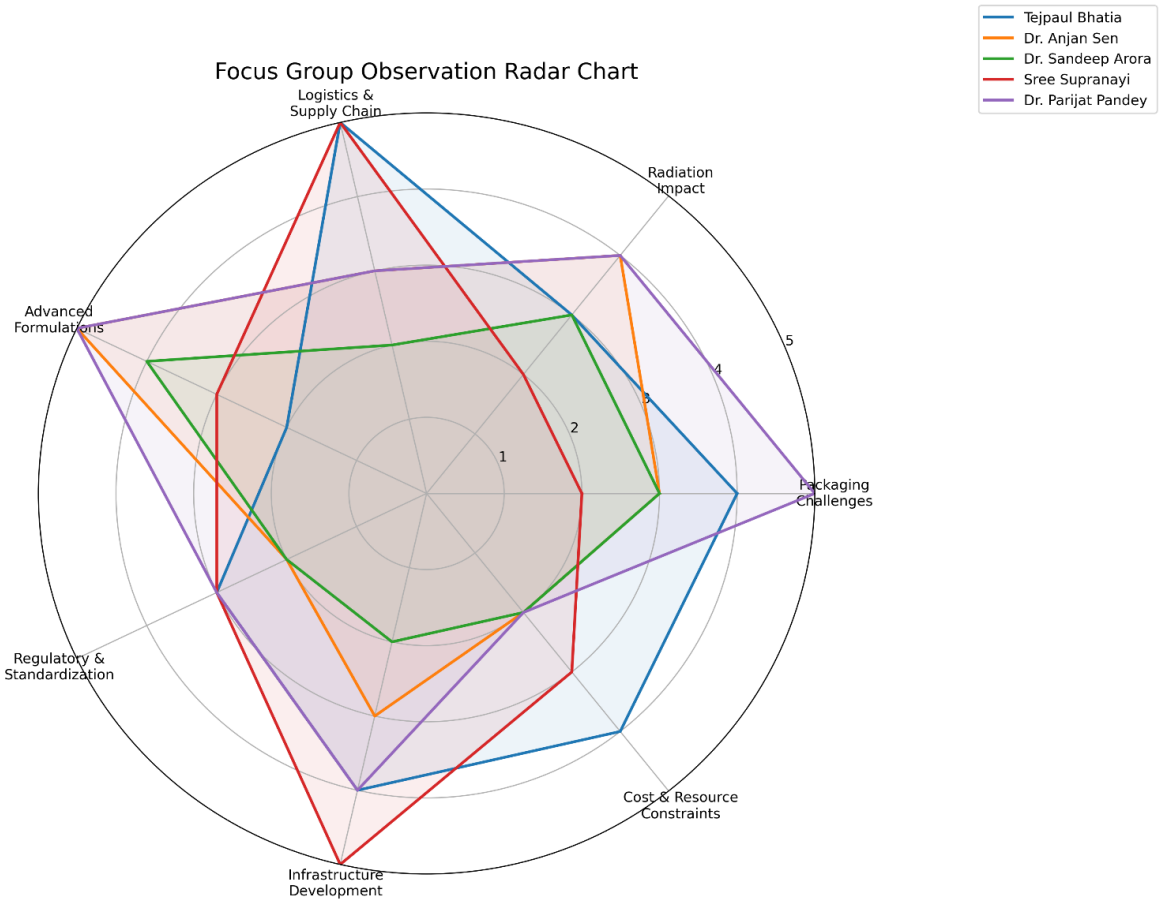

Figure 6: Focus Group Analysis

7. Findings and Suggestions

7.1 Findings

7.1.1 The study found that space environmental conditions such as radiation exposure, microgravity, vacuum pressure, and temperature variations contribute significantly to pharmaceutical degradation and reduced drug effectiveness.

7.1.2 Repackaging medicines before space missions was identified as a major cause of instability because medications become more vulnerable to moisture, oxygen, and contamination after removal from their original protective packaging.

7.1.3 Solid pharmaceutical formulations, including tablets and capsules, were observed to maintain greater stability compared to liquid medicines, which are more susceptible to oxidation and radiation-related degradation.

7.1.4 Existing pharmaceutical shelf-life standards may not adequately support long-duration missions such as future Mars expeditions, creating challenges for maintaining safe and effective medications throughout the mission period.

7.1.5 Experts participating in discussions emphasized that logistical limitations, inadequate infrastructure, and regulatory barriers continue to slow progress in space-based pharmaceutical development and research.

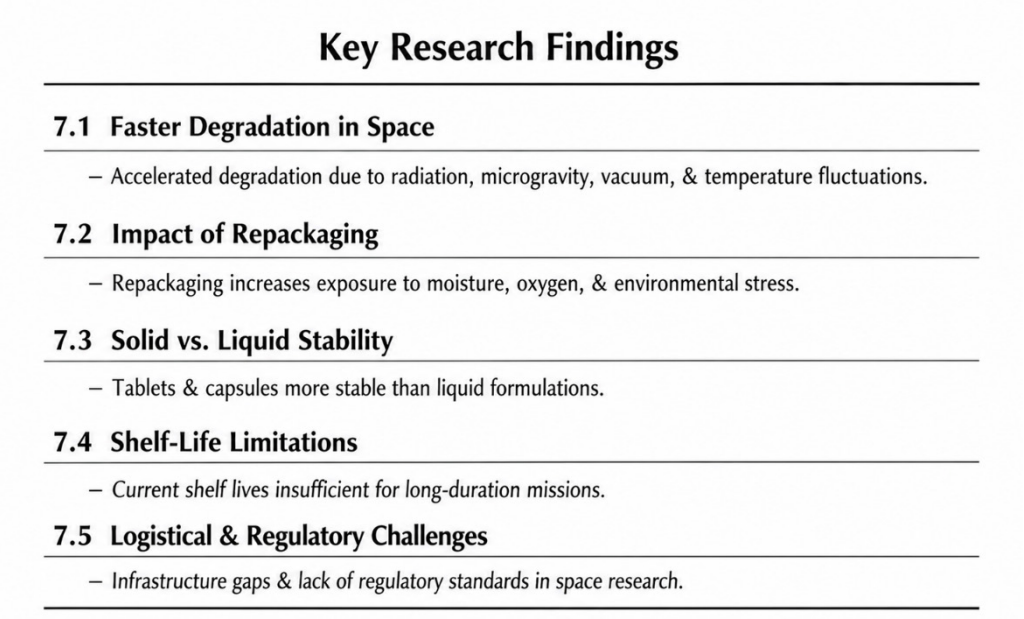

Figure 7: Key Research Findings

7.2 Suggestions

7.2.1 Space agencies and pharmaceutical companies must cooperate together to create sophisticated packaging techniques that protect against radiation and moisture.

7.2.2 Additional research is needed to determine the long-term storage of pharmaceuticals for journeys to Mars and other distant planets in space.

7.2.3 Additional emphasis should be made on the development of space-appropriate medicinal formulations, such as freeze drying, solid state, and three-dimensional printing processes for pharmaceuticals.

7.2.4 ISRO must collaborate with pharmaceutical companies and research bodies to set common regulatory criteria for future pharmacological research in space.

7.2.5 Further study must focus on the practical application of pharmaceutical medications in space technology to healthcare systems in remote locations on Earth.

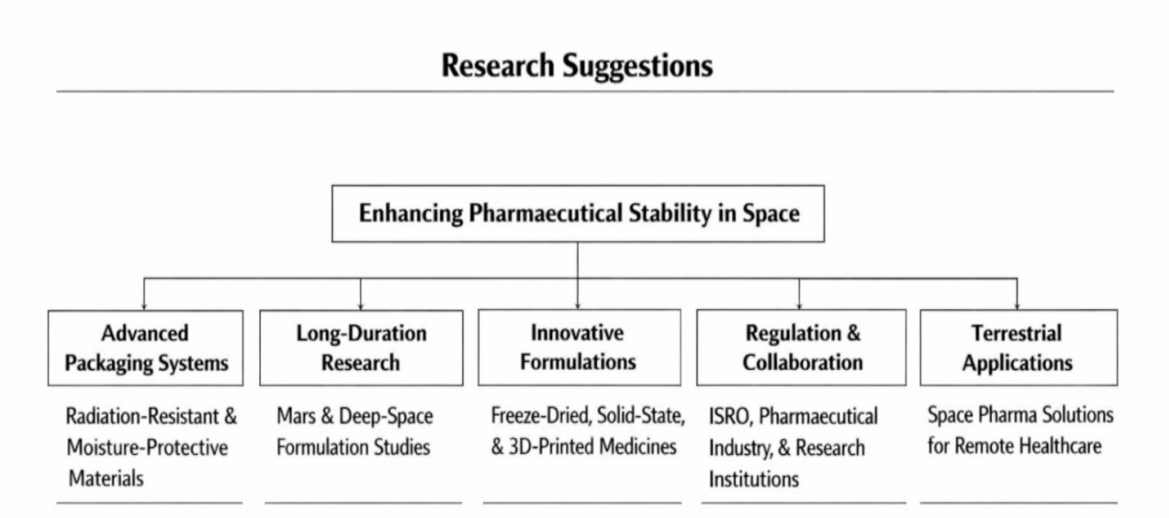

Figure 8: Research Suggestions

8. Conclusion

The success of future long-duration space missions hinges greatly on the availability of safe, reliable, and effective pharmaceuticals for astronauts. This study looked at how space's extreme circumstances, including as radiation, microgravity, vacuum exposure, and storage limits, affect pharmaceutical stability and shelf life. The findings indicate that medications held in space settings are more likely to degrade over time, especially when repackaged prior to launch.

The study also found that formulation type has an essential effect in medication preservation, with solid dosage forms being more resistant to environmental stress than liquid formulations. The study also raised worries about the limited shelf life of many available medicines for long-term missions, such as human travel to Mars.

The study identified many possible ways for enhancing pharmaceutical stability in space based on literature review, expert opinions, and focus group discussions. These include sophisticated packaging systems, radiation protection technologies, freeze-drying processes, nanotechnology applications, and pharmaceutical manufacture using 3D printing. Greater collaboration among space agencies, pharmaceutical businesses, healthcare professionals, and academic institutions will be required for future advancements in this field.

Overall, prolonging the shelf life of pharmaceuticals in space requires not just pharmacological expertise but also logistics, mission planning, and strategic healthcare management. Continued research in this field will benefit both future human space exploration and healthcare solutions in isolated or severe locations on Earth.

Future Scope of Research

Future directions in space pharmaceuticals include developing integrated drug stability models that take into account all environmental simulations such as radiation exposure, microgravity conditions, vacuum effects, and temperature variations, as well as sophisticated predictive analysis using artificial intelligence and machine learning. Another possible path is the on-site production of therapeutic drugs during space trips using 3D

printing and nanotechnology. Furthermore, because long-term trips to Mars and other planets are planned, international standards and collaboration between space agencies, pharmaceutical corporations, and healthcare institutes would be required. Finally, this type of research could be applied in various contexts, such as terrestrial disasters and military situations.

References

Bhayani, D., Mehta, P., Patel, M., Naik, H., Nathaniel, T. N., & Khan, S. (2022). *Ground-based selected ionizing space radiation effects on stability of APIs and their formulations.* Journal of Pharmaceutical and Biomedical Analysis, 220, 115019.

Blue, R. S., Bayuse, T. M., Daniels, V. R., Wotring, V. E., Suresh, R., Mulcahy, R. A., & Antonsen, E. L. (2019). *Supplying a pharmacy for NASA exploration spaceflight: Challenges and current understanding.* NPJ Microgravity, *5*(14), 1–11.

Diaz, T. E., Ives, E. C., Lazare, D. I., & Buckland, D. M. (2024*). Expiration analysis of the International Space Station formulary for exploration mission planning*. NPJ Microgravity, 10(1), article 76.

Du, B., Daniels, V. R., Vaksman, Z., Boyd, J. L., Crady, C., & Putcha, L. (2011). *Evaluation of physical and chemical changes in pharmaceuticals flown on space missions.* The AAPS Journal, 13(2), 299–308.

Du, B., Daniels, V. R., Vaksman, Z., Boyd, J. L., Crady, C., & Putcha, L. (2011). *Evaluation of physical and chemical changes in pharmaceuticals flown on space missions*. AAPS Journal, 13(2), 299–308.

Mehta, P., & Bhayani, D. (2017). *Impact of space environment on stability of medicines: Challenges and prospects*. Journal of Pharmaceutical and Biomedical Analysis, 136, 111-119.

Putcha, L., Berens, K., Marshburn, T., Ortega, H., & Billica, R. (1999). *Pharmaceutical use by U.S. astronauts on space shuttle missions*. Aviation, Space, and Environmental Medicine, 70(7), 705–708.

Reichard, J. F., Phelps, S. E., Lehnhardt, K. R., Young, M., & Easter, B. D. (2023). *The effect of long-term spaceflight on drug potency and the risk of medication failure*. NPJ Microgravity, 9(1), 1–11.

Tran, Q. D., Spooner, N., Geoghehan, S., Thavarajah, S. R., Rahman, S., Tran, N. N., Williams, P. M., Martinez Jarquin, S., Kim, D.-H., Davey, K., Buell, J., Shumbera, M., Gittleman, M., Clements, T., Stoudemire, J., Fisk, I., & Hessel, V. (2025). *Cosmic-ray radiation effects on ibuprofen tablet formulation inside and outside of the International Space Station.* Advanced Healthcare Materials, 14(4), Article 2402361.

Wotring, V. E. (2015). *Medication use by astronauts in spaceflight*. FASEB Journal, 29(11), 4417–4423.

Wotring, V. E. (2016). *Chemical potency and degradation products of medications stored over 550 Earth days at the International Space Station*. AAPS Journal, 18(1), 210–216.

Young, M., Reichard, J. F., Daniels, V., & Wu, H. (2021). *Stability assessment of amoxicillin under simulated galactic cosmic radiation*. Journal of Pharmaceutical Analysis, 11(5), 567–575.