SPACE DEBRIS AND ENVIRONMENTAL LAW IN ORBIT

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ABSTRACT

As humanity expands its presence beyond Earth, the legal structures that regulate outer space need to progress from simply ensuring accountability to embracing proactive stewardship. The Liability Convention of 1972, a fundamental component of space law, implemented the principles of the Outer Space Treaty from 1967 by establishing both absolute and fault-based liability for damages inflicted by space objects. However, the Convention's focus on compensation after damage occurs is becoming insufficient for tackling intricate challenges such as the increase of orbital debris, the pollution from lunar dust, and the risk of contaminating extraterrestrial bodies. Emerging environmental principles, especially the Precautionary Principle, the Polluter Pays Principle, and the Principle of Common but Differentiated Responsibilities (CBDR), provide essential normative guidance for redefining the governance of outer space. By incorporating these principles, international space law could shift from a reactive liability framework to one centered on preventive and restorative justice, highlighting sustainability, collective responsibility, and equity for future generations. The Precautionary Principle advocates for caution amid scientific uncertainty, particularly concerning high-risk endeavors like lunar mining and asteroid extraction. At the same time, CBDR acknowledges that more technologically advanced nations hold greater responsibilities to reduce space debris and protect the shared celestial resources. Additionally, comparisons to terrestrial agreements, such as the Antarctic Treaty System and the 1969 Civil Liability Convention on Oil Pollution, illustrate the viability of collaborative liability frameworks that harmonize exploration with environmental ethics. Merging these Earth focused principles into space law can foster a hybrid legal approach that preserves both human advancement and cosmic ecosystems. Ultimately, transforming the Liability Convention into a preventive, precautionary, and ethically informed instrument would ensure that humanity's quest for the stars is guided by the same ethical standards that safeguard our planet.

Introduction

The momentous occasion of October 4, 1957, when the Soviet Union launched Sputnik-I into orbit, marked the beginning of a new era for humanity, the space age. This event revolutionized science, communication, and the collective imagination of people around the world. Just a few years later, in April 1961, Yuri Gagarin became the first human to journey into outer space, and by 1969, humanity had set foot on the Moon. These significant achievements not only reflected technological advancements but also marked the start of humanity's legal and ethical obligations beyond our planet's atmosphere. The emergence of the Space Age brought with it both awe and reflection. The 1972 Liability Convention, designed with the spirit of accountability, aimed to ensure that nations are held responsible for any damage caused by their space objects. Yet, the current dilemmas, from orbital debris and lunar dust pollution to contamination of other planets, call for a new interpretation. If the legal framework on Earth can evolve from addressing industrial damage to promoting environmental sustainability, why cannot the same be true for space law? The incorporation of the precautionary principle, as highlighted in the Rio Declaration (1992), along with the principle of Common But Differentiated Responsibilities (CBDR) derived from climate governance, implies that advanced spacefaring nations should bear greater responsibilities for mitigating space debris, ensuring planetary protection, and promoting ethical exploration.

The Rising Threat of Space Debris, Among the numerous obstacles.

Among the numerous obstacles that come with space exploration, space debris emerges as one of the most critical dangers. The orbit around Earth has become progressively overcrowded with remnants of human-made objects, which range from abandoned satellites and rocket components to tiny metal particles. These shards travel at speeds that surpass 35,000 kilometers per hour, implying that even a fragment as small as one centimeter can inflict severe damage upon collision. The Kessler Syndrome, also known as the cascade effect, illustrates a situation in which collisions among debris produce additional fragments, resulting in a self-perpetuating chain reaction[1]. This could eventually establish a dense "debris belt" surrounding Earth, rendering space missions hazardous and significantly more costly.[2] Consequently, we could

[1]Donald J. Kessler & Burton G. Cour-Palais, Collision Frequency of Artificial Satellites: The Creation of a Debris Belt, 83 J. Geophysical Res. 2637 (1978).

[2]U.N. Office for Outer Space Affairs, Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space (2010).

enter a time where only heavily fortified or specialized spacecraft can operate safely in orbit. The growing debris problem also has financial implications, increasing insurance costs for space missions and raising the economic risks tied to satellite operations. In addition, the environmental implications such as metal dust contamination and rocket emission particles pose growing concerns under the emerging concept of space environmentalism.

Nuclear contamination and hazards in orbit

A unique aspect of orbital risk comes from satellites powered by nuclear energy. Throughout the Cold War, the Soviet Union placed over 31 nuclear-powered satellites into space. The United States also investigated nuclear propulsion and reactor-driven spacecraft for defense and deep-space exploration. By the late 1980s, it was estimated that more than one ton of enriched uranium-235 and plutonium-238 was orbiting Earth[3]. Most of this hazardous material is located in Low Earth Orbit (LEO), between 900 and 1,000 kilometers, which is the same area used by communication and navigation satellites. The danger of a collision with a nuclear-powered satellite could result in the release of radioactive particles, creating both a contamination risk in orbit and a potential danger to Earth's biosphere through debris during re-entry. This combination of technological progress and environmental threat has prompted calls for more stringent international regulations under the Outer Space Treaty (1967) and the Liability Convention (1972) to oversee not only mechanical damage but also environmental and biological contamination.

What Counts as a Space Object and Damage

The phrase "space object" is primarily defined in the Convention on Registration of Objects Launched into Outer Space, 1975 (Registration Convention) and is also referred to in the Convention on International Liability for Damage Caused by Space Objects, 1972 (Liability Convention). According to Article I(d) of the Liability Convention, a "space object" encompasses not only the main space object itself but also its launch vehicle and any components associated with it[4]. This definition is intentionally broad, including satellites, launch vehicles, and even pieces of debris or fragments that arise from explosions or collisions. Therefore, if a small fragment dislodged from a rocket stage causes damage, it continues to be

[3]John Pike, Nuclear Power in Space, Federation of Am. Scientists (1986).
[4]Convention on International Liability for Damage Caused by Space Objects art. I(d), Mar. 29, 1972, 961 U.N.T.S. 187.

considered a space object under international law. The Liability Convention elaborates on the term "damage" in Article I(a), stating it encompasses "loss of life, personal injury, or any other impairment of health; as well as loss or destruction of property belonging to States or individuals, whether natural or legal persons, or property owned by international intergovernmental organizations."[5] Therefore, under international space law, damage can be categorized into: personal harm, such as death, injury, or health deterioration; and property damage, which includes the loss or harm to tangible assets on Earth, in airspace, or in outer space (including satellites and space stations). However, environmental harm or contamination is not clearly defined as "damage" unless it leads to measurable physical injury. This limitation is increasingly viewed as obsolete, particularly regarding issues like lunar dust pollution, rocket emissions, and Martian microbial contamination that may endanger future ecosystems or missions.

Case Example: The Cosmos 954 Incident (1978).

A significant instance of "space object" and "damage" in action is the Cosmos 954 Incident. In January 1978, a Soviet satellite powered by nuclear energy re-entered the Earth's atmosphere, scattering radioactive debris across a large area of Canada. Canada submitted a claim under the Liability Convention, asserting that the USSR was strictly liable for the contamination.[6] The case resulted in a settlement of C$3 million, highlighting both the effectiveness and the limitations of the Convention. It established that both the satellite and its radioactive debris were classified as space objects, and that radioactive fallout was legally recognized as damage. Nevertheless, the limited definition meant that the long-term environmental consequences were not legally addressed.

The Concept of Damage is Evolving in the 21st Century.

As private companies like SpaceX, Blue Origin, and ISRO engage in commercial activities, the conventional understanding of space objects and associated damage must adapt. Future legal regulations should consider: Environmental pollution (such as emissions from rockets and the dispersion of lunar dust), Biological contamination resulting from planetary exploration missions, The creation of orbital debris and the potential for cascading collisions,

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[5] Id. art. I(a).

[6] Canada Union of Soviet Socialist Republics: Settlement of Claim for Damage Caused by "Cosmos 954," 18 I.L.M. 899 (1979).

Accountability for autonomous or AI-driven spacecraft that fail without human interference. Incorporating environmental principles, such as the precautionary principle and the polluter-pays doctrine outlined in the Rio Declaration (1992), may provide a connection between Earth-based environmental legislation and the governance of outer space.

No Liability in the Cosmos: The Principle of Absolute Liability

According to Article II, a launching State is completely liable for any damage inflicted by its space object on the surface of the Earth or to aircraft in operation[7]. This principle eliminates the necessity to demonstrate negligence; the simple fact of harm is enough to assign responsibility. This rule mirrors the strict liability doctrine found in nuclear and environmental legislation, which mandates that those who engage in highly hazardous activities are responsible for any potential damage[8]. The incident involving Cosmos 954 in 1978 serves as a practical illustration of this principle: a nuclear-powered satellite from the Soviet Union re-entered Earth's atmosphere, dispersing radioactive debris throughout Canada. Canada utilized the Liability Convention and attained a C$3 million settlement[9]. This case reinforced the understanding that the obligation to provide compensation crosses national frontiers and encompasses technological failures.

Fault Among the Stars: Negligence and Collisions in Space

When damage occurs in outer space, Article III enforces liability based on fault, which only comes into play if negligence, recklessness, or intent can be established.[10] This reflects the progression of tort law, which transitioned from "act at your peril" to a foundation of fault-based ethics[11]. The reasoning of Lord Atkin in Donoghue v. Stevenson remains relevant: "You must take reasonable care to avoid acts or omissions that you can reasonably foresee would likely harm your neighbor."[12]In the context of space, this "neighbour" principle obliges operators to: Manage spacecraft with care, Adhere to debris-mitigation practices, Share collision-avoidance information; and ensure the safe disposal of satellites following their

[7]Convention on International Liability for Damage Caused by Space Objects art. II, Mar. 29, 1972, 961 U.N.T.S. 187.
[8]P. S. Rao, International Liability for Injurious Consequences Arising out of Acts Not Prohibited by International Law (1990).
[9] Liability Convention art. VI.
[10]Liability Convention art. III.
[11]John H. Wigmore, A Panorama of the World's Legal Systems (Washington Law Book Co. 1936).
[12]Donoghue v. Stevenson, [1932] A.C. 562 (H.L.).

operational lifespan. The Iridium Cosmos collision (2009), which resulted in the destruction of both satellites and the creation of countless debris fragments, exemplifies the repercussions of insufficient coordination and the challenges of establishing fault in orbit.[13]

Earthly Lessons, Celestial Duties: Comparisons Between Environmental and Maritime Law

The framework of the Liability Convention reflects established terrestrial models. The polluter-pays principle outlined in the Rio Declaration (1992) and the oil-pollution liability framework of the 1969 Civil Liability Convention similarly place accountability on those who generate environmental risks.[14] Just as ship owners are obligated to avert oil spills, spacefaring nations are tasked with preventing the accumulation of orbital debris. Employing the precautionary principle, which advocates for harm prevention even in the face of uncertainty, could influence future applications of the Convention in favor of sustainability. [15]

The 1969 International Convention on Civil Liability for Oil Pollution Damage stands as another valuable example. Ship owners are mandated to both prevent oil spills and compensate those impacted, akin to how States are required to prevent and address space debris issues. [16]Both regulatory frameworks share a common philosophy: those who gain from potentially dangerous practices also bear their environmental and societal repercussions.

Expanding Liability: From Oceans to Orbits

The principle of Common but Differentiated Responsibilities (CBDR) may not be explicitly defined within space law, but it provides significant moral and structural insights. It recognizes that while all nations are responsible for safeguarding global commons, their obligations should correspond to their varying capabilities and historical roles in causing environmental damage.[17] When applied to outer space, CBDR suggests that technologically advanced countries with strong space sectors and extensive launch facilities should take the lead in addressing orbital debris and ensuring a safe and sustainable exploration of space. The United Nations Convention on the Law of the Sea (UNCLOS) further strengthens this comparison. Just as

[13]Iridium–Cosmos Collision (2009), NASA Orbital Debris Q. News, Vol. 13, No. 2.
[14]Rio Declaration on Environment and Development, princ. 16 (1992).
[15]Liability Convention art. I(c).
[16]International Convention on Civil Liability for Oil Pollution Damage, Nov. 29, 1969, 973 U.N.T.S. 3 (entered into force June 19, 1975).
[17]United Nations Framework Convention on Climate Change, princ. 7 (1992).

coastal nations are required to protect the marine environment beyond their territorial boundaries, countries engaged in space activities can be seen as “guardians of orbit,” responsible for preserving the extraterrestrial environment for future generations.[18] The integration of the CBDR principle into outer space law resonates with the concept of “the province of all humankind” found in Article I of the Outer Space Treaty (1967), which states that the exploration and utilization of outer space should benefit and serve the interests of all nations[19]. This wording reflects the environmental justice principles underlying CBDR: while all countries should have access to and derive benefits from outer space, those with greater resources have a greater duty to protect it. Countries like the United States, Russia, China, Japan, and members of the European Space Agency (ESA) are responsible for over 90% of the objects launched into orbit[20]. Their disproportionate utilization of the orbital space is akin to the concept of “historical emissions” in climate legislation. Therefore, just as developed nations are expected to lead in climate change efforts, primary spacefaring countries should accept greater responsibilities in debris management, sustainable satellite design, and remediation actions.

From Climate Burden to Cosmic Burden: Equity in the Stars CBDR

CBDR also represents a principle of intergenerational equity, which is becoming increasingly significant in discussions about sustainable practices in space. Unlike pollution on Earth, space debris can linger in orbit for decades, or even centuries, impacting future generations of space explorers and researchers[21]. As a result, the concept of equity within CBDR should not only focus on current nations but also consider the rights of those who will utilize space in the future. This philosophical perspective redefines outer space as a communal asset for future generations, where fairness should extend across both time and location. Moreover, as private entities continue to deploy thousands of satellites each year, the threat of orbital overcrowding and unequal access grows more pronounced. In the absence of a framework for differentiated responsibilities, powerful corporations could monopolize orbital positions and resources,

[18]United Nations Convention on the Law of the Sea, Dec. 10, 1982, 1833 U.N.T.S. 397 (entered into force Nov. 16, 1994).
[19]Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies, Jan. 27, 1967, 610 U.N.T.S. 205 (entered into force Oct. 10, 1967), art. I.
[20]European Space Agency, Space Debris by the Numbers (2024), https://www.esa.int/Safety_Security/Space_Debris/Space_debris_by_the_numbers (last visited Nov. 3, 2025).
[21]Donald J. Kessler & Burton G. Cour-Palais, Collision Frequency of Artificial Satellites: The Creation of a Debris Belt, 83 J. Geophysical Res. 2637 (1978).

sidelining developing countries. [22]If adapted, CBDR could function as a balancing mechanism that promotes fair involvement and prevents a widening "celestial inequality gap." Although existing space agreements do not explicitly include CBDR terminology, instruments of soft law like the UN Guidelines for the Long-term Sustainability of Outer Space Activities (2019) and the COPUOS Debris Mitigation Guidelines (2007) implicitly acknowledge differentiated obligations.[23] Future changes, possibly in the form of a "Space Sustainability Protocol" linked to the Liability or Registration Conventions, could formalize CBDR by mandating major launch nations to disclose their environmental impacts, contribute to cleanup efforts, and aid developing nations in creating infrastructure that minimizes debris. Additionally, CBDR could influence how disputes are resolved under the Liability Convention, where proportional responsibility might take the place of uniform liability standards. This approach would ensure that nations that contribute more significantly to orbital pollution bear a larger share of the responsibility for compensation and mitigation, promoting a fair and forward-thinking strategy in the dynamic "space economy."[24]

The Precautionary Principle Among the Stars: Anticipating Harm Before It Reaches Orbit

The precautionary principle, a fundamental element of contemporary international environmental law, requires states to implement preventive actions when there is a possibility of severe or irreversible damage, even when scientific certainty is lacking. [25]This principle came to the forefront of international discussion with Principle 15 of the Rio Declaration on Environment and Development (1992), which asserts that "when there are threats of serious or irreversible damage, the absence of full scientific certainty should not be used as justification for delaying cost-effective actions to avert environmental degradation.[26]" When applied to space activities, this principle takes on additional complexities. In contrast to terrestrial ecosystems, environments such as the lunar surface, asteroid belts, and Martian biosphere remain largely uncharted and scientifically vulnerable. The entry of human technology, mining apparatus, or biological materials into these untouched locations could result in irreversible

[22]Christopher D. Johnson, Who Owns the Orbit? Private Actors and the Equity Challenge in Space Law, 44 Space Pol'y 101 (2020).
[23]U.N. Comm. on the Peaceful Uses of Outer Space, Space Debris Mitigation Guidelines (2007).
[24]Bin Cheng, Studies in International Space Law (Clarendon Press 1997).
[25]Philippe Sands, Principles of International Environmental Law 217 (4th ed. 2018).
[26]Rio Declaration on Environment and Development, U.N. Doc. A/CONF.151/26/Vol. I, princ. 15 (June 14, 1992).

contamination or disruption of celestial environments.[27] Therefore, the precautionary approach necessitates that states and private entities assess long-term impacts before initiating extensive space exploitation.

The Unseen Hazards of Lunar Dust and Surface Contamination

Recent studies by NASA and ESA indicate that lunar dust (regolith), which consists of ultra-fine, sharp silicate particles, presents significant risks to both human health and technological systems. When inhaled, these tiny particles can become lodged deep within lung tissue, leading to effects similar to those caused by silicosis or asbestos exposure[28]. During the Apollo missions, astronauts experienced symptoms such as "lunar hay fever," skin irritation, and mechanical failures in seals and joints due to dust contamination.[29] The abrasive and electrostatic characteristics of lunar dust also jeopardize the integrity of long-term habitation structures, solar panels, and vehicle mechanisms. The threat goes beyond health concerns: once released into the lunar atmosphere, these particles can compromise instruments designed to study the Moon's natural condition, resulting in data distortion and posing a subtle yet significant risk to environmental integrity. [30]The COSPAR Planetary Protection Policy (revised in 2021) emphasizes that even minor biological or particulate contamination of celestial bodies can irreversibly affect investigations into astrobiology. [31]The introduction of Earth-based microbes to Mars or Europa, whether through unsterilized equipment or unintentional human presence, could complicate future life detection missions, rendering them scientifically compromised[32].

Conclusion

Exploration is intrinsic to humanity; safeguarding our discoveries must be our guiding principle. The future of space law relies not only on determining liability after damage occurs but also on taking proactive measures to avert harm before it happens. By drawing from the Antarctic Treaty's moratorium model and COSPAR's standards for planetary protection, an

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[27]Fabio Tronchetti, Fundamentals of Space Law and Policy 89 (2013).
[28]James L. Gaier, The Hazards of Lunar Dust, NASA Tech. Paper No. 2005–213610 (2005).
[29]Harrison H. Schmitt, The Challenge of the Lunar Environment in a Return to the Moon, 2 Advances in Space Research 212 (2006).
[30]ESA Space Safety Programme, Lunar Dust Mitigation Report (ESA/TEC-SAF 2020).
[31]Committee on Space Research (COSPAR), Planetary Protection Policy (2021 rev.).
[32]Margaret Race & Catharine Conley, Legal and Ethical Issues in Planetary Protection, 46 Space Pol'y 10 (2015).

approach that prioritizes caution, equity, and research should form the foundation of upcoming treaties. The universe, much like our planet, is a collective legacy. Our legal frameworks need to embody this reality, ensuring that human aspirations do not surpass our responsibilities toward the planets.