Orbital Debris: Technical and Legal Issues and Solutions

by

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ABSTRACT

This thesis examines the current technological and legal issues concerning orbital debris (space debris). The unique physical characteristics of the space environment are identified and explained. The thesis then explores the causes of orbital debris and examines the risk posed by debris to the most frequently used orbital areas. Significant environmental, legal, political, and economic consequences of orbital debris are described. The current technical and legal controls on the creation of debris are discussed and evaluated. Finally, proposed solutions are considered and critiqued. The thesis concludes with a non-binding treaty-based proposal for a new legal debris control regime that can encourage compliance and enhance accountability.

RÉSUMÉ

Cette thèse examine les questions technologiques et légales concernant le débris spatial. Les caractéristiques uniques et physiques de l'environnement spatial sont identifiées et expliquées. La thèse explore ensuite les causes du débris spatial et examine les risques posés par le débris dans les régions spatiales les plus fréquemment utilisées. Les conséquences du débris spatial sur les questions environnementales, légales, politiques et économiques sont décrites. Les contrôles techniques et légaux sur la création du débris spatial sont discutés et évalués. Finalement les solutions proposées sont considérées et critiquées. Cette thèse conclue avec une proposition basée sur un traité non-contraignant pour un nouveau régime de contrôle légal de débris qui encouragera l'obéissance et augmentera la responsabilité.

ACRONYMS AND ABBREVIATIONS

COPUOS	Committee on the Peaceful Uses of Outer Space
DoD	United States Department of Defense
DOT	United States Department of Transportation
ESA	European Space Agency
FCC	United States Federal Communication Commission
GEO	Geosynchronous Orbit
GPS	Global Positioning System
GTO	Geosynchronous Transfer Orbit
HEO	Highly Elliptical Orbit
IADC	Interagency Space Debris Coordination Committee
ICAO	International Civil Aviation Organization
ICJ	International Court of Justice
ISO	International Organization for Standardization
ITU	International Telecommunications Union
LEO	Leo Earth Orbit
MEO	Medium Earth Orbit
NASA	United States National Aeronautics and Space Administration
NDAA	United States National Defense Authorization Act
NEPA	United States National Environmental Policy Act
NOAA	United States National Oceanic and Atmospheric Administration
NPS	Nuclear Power Sources
ODCWG	Orbital Debris Coordination Working Group
SSN	United States Space Surveillance Network

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I. Introduction

Outer space is becoming cluttered with litter. For nearly fifty years, people have been launching rockets into space, in orbit around Earth, and beyond. The remains of derelict satellites and rockets and the debris resulting from their explosions and collisions with one another constitute a significant fraction of the objects in space—far larger in number and mass than spacecraft that are still operational. These derelict objects, usually called space debris or orbital debris, are essentially polluting the space environment by their mere presence. Since at least the late 1980s, scientists and legal commentators have been calling for States and the international community to take action to prevent the creation of new debris.

This thesis reviews those efforts, with special emphasis on events since 2002 and focusing only on artificial space debris in orbit around Earth. Artificial debris is created by humans and is distinguishable from natural debris such as meteoroids. Space debris in orbit around the Earth, usually called orbital debris to differentiate it from debris in other regions of space, presents the most serious current threat to the use of space.[1] The processes by which orbital debris is created and the methodologies used to study orbital debris, to analyze the risks, and to develop strategies for combating the effects of orbital debris are highly technical in nature. Anyone interested in the legal issues presented by orbital debris must have a basic understanding of the physics and technologies involved.

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[1] Nevertheless, as activities in other areas increase, the problem of debris will undoubtedly spread. For example, the Moon is littered with over 100,000 kilograms of man-made debris resulting from more than 50 lunar landings and impacts. Nicholas L. Johnson, "Man-Made Debris In and From Lunar Orbit" (Paper presented to the 50th International Astronautical Congress Meeting in Amsterdam, The Netherlands, 4-8 October 1999), IAA-99-IAA.7.1.03 [unpublished] at 8-9. Also, the Mars Reconnaissance Orbiter recently entered orbit around Mars and has had to do an "interesting little dance" to avoid other active and inactive spacecraft orbiting Mars. Leonard David, "The Tricky Task of Aerobraking at Mars" *Space.com* (30 May 2006), online: <http://www.space.com/scienceastronomy/060530_science_tuesday.html>.

Additionally, solutions to the problem of orbital debris are both legal and technical in nature and must be considered together. Therefore, this thesis uses current scientific research into the issues of orbital debris as the basis for analyzing existing and proposed legal regimes.

Part II of this thesis contains an overview of the basic technical background necessary to understand the issues. It begins with a discussion of the unique characteristics of the space environment and discusses the properties of the major areas used by Earth-orbiting spacecraft. Part II concludes with a presentation of the sources and types of orbital debris as well as quantification of the level of risk posed by it. Part III catalogs some of the many technical, legal, political, and economic consequences of orbital debris. Part IV presents the technical and legal regimes that are currently being used to combat the problem of orbital debris. It also contains a review of international law as well as the laws and policies of international organizations and major space-faring States. Part V analyzes the level of success achieved by the current technical debris mitigation measures and legal practices. Finally, Part VI surveys a number of proposed legal solutions as well as posits an alternative solution.

II. Technical Background

In order to understand the sources and problems of orbital debris, some technical background is essential. This Part reviews the physical characteristics of the space environment, commonly used orbits, and major sources of orbital debris.

A. The Space Environment

Science fiction movies and literature make space travel appear analogous to flying in an airplane or riding a ship. Those analogies are not particularly accurate. Space has its own physical properties that make it unique and outside the experience of most people. Space is a harsh environment that limits the functional lifetime of satellites, which has important consequences on the amount of orbital debris that is created. Commercial satellites have an average lifespan of 15 years.[2] Environmental factors can degrade the performance of a satellite, shortening its lifespan. Old satellites remain in space as debris until they are intentionally removed from orbit or returned to Earth through natural forces. New satellites sent to replace the old ones also create new debris.

These features of the space environment are directly related to the causes and effects of orbital debris. A number of factors are important and will be discussed, but the most important is Earth's gravity. Gravity and laws of motion govern the behavior of objects in outer space in predictable ways. Working within these principles, spacecraft designers and operators can use certain areas of the space near Earth to their advantage.

1. Gravity

It is elementary science that the Earth's gravity pulls all objects towards it. With appropriate speed and direction,[3] a rocket can counteract the force of gravity. It is the combination of velocity and gravity that determines an object's orbit (or altitude above Earth). Without enough velocity, all objects will return to Earth's surface.[4] With too

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[2] *Hearings on Commercial Space Transportation Before the Subcomm. on Aviation of the House Comm. on Transportation and Infrastructure*, 109th Cong., 1st Sess. (2005) (statement of John W. Douglass, President and Chief Executive Officer, Aerospace Industries Association of America) (Lexis, HEARNG).

[3] The combination of speed and direction is called velocity.

[4] The minimum velocity for an object in an orbit close to Earth is approximately seven kilometers per second, or about 30 times faster than a Boeing 747 aircraft travels. David Wright, Laura Grego, & Lisbeth Gronlund, *The Physics of Space Security: A Reference Manual* (Cambridge: American Academy of Arts and Sciences, 2005) at 20, online: <http://www.amacad.org/publications/Physics_of_Space_Security.pdf>. Satellites have a lower orbital velocity the farther they are from Earth. For example, in a geosynchronous orbit (35,786 kilometers above Earth), orbital velocity is only about four kilometers per second. *Ibid*. at 21.

much velocity, an object will escape Earth's gravity altogether.[5] In either case, the object will not maintain an orbit around Earth.[6] With the proper velocity, however, a satellite can be placed into orbit around Earth in a desirable location. Once in orbit, a satellite will remain in that orbit until it is acted on by external forces or until it takes action to change its own velocity.[7] If Earth were a perfect sphere and there were no other large objects in the solar system, that would be the end of the explanation. However, Earth is not a perfect sphere and its gravitational field is asymmetrical and perturbs a satellite's orbit slowly over time.[8] The gravity of the Sun, the Moon, and Jupiter also causes subtle changes to a satellite's orbit; the farther the satellite is from Earth, the more noticeable the effect.[9]

2. Earth's Atmosphere and Magnetic Field

There is no single point at which Earth's atmosphere may be said to end and space begin. The atmosphere thins with altitude and most of the atmospheric particles end by 100 kilometers, the generally accepted altitude at which space begins.[10] However, the effects of atmospheric drag on satellites continue for another several hundred kilometers.[11] Although the drag is very slight, the cumulative effect over time will lower a satellite's altitude.[12] Furthermore, during peak periods of solar activity, the outer layers

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[5] Escape velocity is approximately 11.2 kilometers per second. *Ibid*. at 20.

[6] James E. Oberg, *Space Power Theory* 20, online: <http://space.au.af.mil/books/oberg/ch01app1.pdf>.

[7] Wright, *supra* note 4 at 19.

[8] *Ibid.* at 40.

[9] *Air University Space Primer* (Maxwell AFB, AL: Air University, 2003), Chap. 8, at 22-23, online: <http://space.au.af.mil/primer/orbital_mechanics.pdf>.

[10] See Bin Cheng, *Studies in International Space Law* (Oxford: Clarendon Press, 1997) at 396-7. The lowest recorded altitude of a satellite's orbit was 96 kilometers. *Ibid*.

[11] Cheng, *supra* note 10 at 18. The effects of the atmosphere are virtually nonexistent by 1,000 kilometers. *Ibid*.

[12] Wright, *supra* note 4 at 39.

of Earth's atmosphere expand outward, increasing the amount of drag in unpredictable ways.[13] Therefore, satellites in low orbits must carry fuel to raise their altitude and maintain the desired orbit.[14] When the satellite runs out of fuel or malfunctions and can no longer maneuver, its orbit will decrease over time, subject to natural forces.

Earth's magnetic field also affects the orbits of satellites. The electronics on board satellites interact with Earth's magnetic field to produce a small magnetic field of their own, causing torque on the satellites.[15] The effect, however, is very small and is most noticeable in satellites orbiting close to Earth.[16]

3. Radiation

Without Earth's atmosphere to protect them, satellites are exposed to the full force of solar radiation. The types of radiation include ultraviolet rays and X-rays as well as positively charged protons and negatively charged electrons.[17] Ultraviolet rays and X-rays can damage satellites by degrading solar panels, which many satellites use as a source of energy, thus shortening their useful life.[18] When solar activity increases, the amount of rays also increases. They are otherwise generally evenly distributed in the space around Earth.[19] The charged particles can cause even more damage than the rays because the particles penetrate the outer layers of the satellite and directly degrade its

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[13] *Ibid.* at 40. Although solar activity acts to expand the outer layer of atmosphere, the greenhouse gas carbon dioxide acts to contract it. H.G. Lewis, "Response of the Space Debris Environment to Greenhouse Cooling," in D. Dansey, ed., *Proceedings of the 4th European Conference on Space Debris Held 18-20 April 2005* (The Netherlands: ESA Publications Division, 2005) at 243. One computer model estimated that carbon dioxide emissions could increase the orbital lifetime of debris located between 250 and 1,200 kilometers above Earth by up to 24 percent by the year 2101. *Ibid*. at 248.

[14] Wright, *supra* note 4 at 40.

[15] *Air University Space Primer*, *supra* note 9 at Chap. 8, 23.

[16] *Ibid*.

[17] Wright, *supra* note 4 at 37.

[18] *Ibid*.

[19] *Ibid*.

electronic systems. Unlike the rays, the particles become trapped in Earth's magnetic field and concentrate in two doughnut-shaped (torus) areas around the equator; these regions are called the Van Allen radiation belts.[20] The Van Allen radiation belts create significant limitations on the operation of satellites.

The inner Van Allen belt extends from approximately 500 kilometers to 5,500 kilometers above Earth's surface with the highest concentration of particles at around 3,000 kilometers. The particle density is greatest at the equator and deceases with increasing latitude toward the north and south poles.[21] Areas with the highest particle density are so dangerous that both manned and unmanned spacecraft avoid those areas.[22] The outer Van Allen belt extends from approximately 12,000 kilometers to 22,000 kilometers, with the heaviest concentration between 15,000 kilometers to 20,000 kilometers.[23] As with the inner Van Allen belt, the particle density is highest at the equator and falls off with increasing latitude.[24] The region between the two belts contains few charged particles.[25] Above the Van Allen belts, the charged protons and electrons create a "solar wind" which exerts pressure on satellites that can perturb their orbit.[26]

4. Natural Debris

As the Earth moves around the sun, it encounters significant amounts of natural debris from comets, asteroids, dust, and other sources. During collisions, this debris can

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[20] *Ibid*.
[21] *Ibid*.
[22] *Ibid*.
[23] *Ibid*.
[24] *Ibid*. at 37-38.
[25] *Ibid*. at 38.
[26] *Air University Space Primer, supra* note 9 at Chap. 8, 23.

degrade a satellite's solar panels, or if the debris is large enough, can penetrate into the interior of a spacecraft and destroy it.

B. Useful Orbits

For a variety of reasons, satellites tend to congregate in certain well-defined regions around the Earth. The mission of the satellite is probably the most important factor in determining the orbit. However, mass and fuel limitations, radiation levels, and orbital mechanics also play important roles. These factors have important consequences for the issue of orbital debris because the most useful orbits have also become the most congested. As these same orbits continue to be used again and again, the problem of orbital debris in these areas increases. Each of the major orbits will be discussed, but Low Earth Orbit and Geosynchronous Earth Orbit are the two most heavily used and are therefore the most significant.

1. Low Earth Orbit (LEO)

LEO is typically defined as any orbit up to around 5,500 kilometers in altitude.[27] Satellites in LEO circle the Earth approximately once every 90 minutes and can be in any inclination (or orbital plane).[28] Many different types of satellites use LEO. Remote sensing satellites, whether used for commercial or military purposes, typically use LEO since it is close to Earth and the cameras or radars get better resolution than they would in higher orbits. All manned spaceflight, except for the United States Apollo lunar

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[27] United States, Office of Science and Technology Policy, *Interagency Report on Orbital Debris* (Washington, 1995) [*Interagency Report*] at 4. Few satellites operate at the higher LEO orbits because of the radiation problem. Wright, *supra* note 4 at 40.

[28] The inclination of an orbit determines what part of Earth the satellite will pass over. Wright, *supra* note 4 at 24. Satellites in equatorial orbits will only pass over the equator. Satellites in polar orbits will pass over all parts of the Earth, the frequency of which is dependent upon the satellite's altitude and how elliptical the orbit is. *Ibid*. The inclination angle of all other orbits determines how far above and below the equator the satellite will travel during each orbit. *Ibid*.

exploration program, also takes place in LEO. Some communications satellites also use LEO, even though the satellites move rapidly across the sky (from the position of an observer on the ground) necessitating a large number of satellites to have global coverage.[29] Finally, LEO is used for certain experimental satellites as well as scientific research satellites.

The length of time that orbital debris will remain in LEO depends on its altitude, mass, size, and the amount of solar activity.[30] A rough estimate of the average life of orbital debris in an altitude between 200 and 400 kilometers is a few months.[31] As debris gets closer to Earth, its rate of orbital decay increases as the atmospheric drag increases and the debris loses speed. For altitudes between 400 and 900 kilometers, the lifespan ranges from a few years to a few hundred years.[32] For debris 2,000 kilometers above Earth, the lifespan is estimated to be 20,000 years.[33]

2. Geosynchronous Earth Orbit (GEO)

Unlike LEO satellites which complete many orbits in a day, satellites in GEO orbit the Earth once a day.[34] There are different types of GEO orbits, but the one most commonly used is called geostationary, which is a circular orbit around the equator at an altitude of 35,786 kilometers.[35] A geostationary satellite appears as a fixed point to all

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[29] *Ibid.* at 41. For example, the Iridium satellite constellation uses 66 satellites. *Ibid*.
[30] *Interagency Report*, *supra* note 27 at 6.
[31] *Ibid*.
[32] *Ibid*.
[33] Luboš Perek, *Discussion Paper* (presented to the Proceedings of the Workshop on Space Law in the Twenty-first Century held in Vienna, Austria, July 1999), U.N. Doc. A/CONF.184/7, 1999, 189 at 190 [Perek, *Discussion Paper*].
[34] Wright, *supra* note 4 at 43.
[35] *Ibid*.

observers on the ground 24 hours a day.[36] Satellites in a geostationary orbit can "see" nearly half the Earth, which makes this orbit especially useful for broadcasting, weather, and telecommunications satellites.[37]

Within the geostationary orbit, certain areas tend to be more congested than others. For example, there are relatively narrow bands of the orbit from which a television broadcasting satellite can reach both the east and west coasts of North America or a telecommunications satellite can communicate with both the east coast of North America and the west coast of Europe. For obvious reasons, these positions are highly coveted and are the locations where satellites tend to cluster.[38] However, the number of satellites that can be placed in these desired regions is finite because satellites must maintain separation from each other in order to avoid collisions and in order to avoid radio communication frequency interference.[39] Because of the special nature of GEO, it is subjected to a unique legal regime administered by the International Telecommunications Union (ITU).[40]

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[36] *Ibid*.

[37] *Ibid*.

[38] Lawrence D. Roberts, "A Lost Connection: Geostationary Satellite Networks and the International Telecommunications Union" (2000) 15 Berkeley Tech. L.J. 1095 at 1102 [Roberts, "A Lost Connection"].

[39] *Ibid*. at 1102-1103.

[40] *Constitution of the International Telecommunications Union*, 22 December 1992, 1825 U.N.T.S., 31251, art. 44(2), online: < http://www.itu.int/aboutitu/basic-texts/constitution/chapter7/chapter07_44.html> (as amended in 1994, 1998, and 2002). Article 44(2) declares:

> In using frequency bands for radio services, Member States shall bear in mind that radio frequencies and any associated orbits, including the geostationary-satellite orbit, are *limited natural resources* and that they must be used rationally, efficiently and economically so that countries or groups of countries may have *equitable access* to those orbits and frequencies, taking into account the special needs of the developing countries and the *geographical situation* of particular countries."

(emphasis added). See also Roberts, *supra* note 38 at 1105; Paul B. Larsen, *et al.*, "DBS Under FCC and International Regulation" (1984) 37 Vand. L. Rev. 67 at 99.

Orbital debris in GEO is estimated to last anywhere from a million to 10 million years.[41] Unlike LEO, objects in GEO are not naturally removed from orbit by atmospheric drag. Instead, the debris moves in an enormous doughnut shaped ring around the equator as the gravitational forces of the Sun, Moon, and Earth pull on the objects.[42] Functioning GEO satellites with remaining fuel sources use station-keeping maneuvers to counteract the gravitational forces and maintain stable locations.

3. Medium Earth Orbit (MEO)

MEO is the region between LEO and GEO, or from about 5,500 kilometers to about 36,000 kilometers.[43] The major types of satellites that use this orbit are those that provide services for navigation systems, such as the United States (US) Navstar Global Positioning System (GPS) and the Russian Glonass satellites.[44] The European Space Agency's proposed fleet of Galileo navigation satellites will also be placed into MEO.[45] These satellites orbit Earth at an altitude of about 20,000 kilometers, in an area of peak density in the outer Van Allen radiation belt. Therefore, these satellites require extra shielding and radiation-hardened components.[46]

4. Other Earth Orbits

At least three other orbits for highly specialized functions have been developed. They are mentioned here for the sake of completeness and to illustrate the other regions in space where satellites tend to cluster. The first is geosynchronous transfer orbit

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[41] *Interagency Report*, *supra* note 27 at 8; Howard A. Baker, *Space Debris: Legal and Policy Implications* (Dordrecht, The Netherlands: Martinus Nijhoff Publishers, 1989) at 26 [Baker, *Space Debris*].

[42] *Interagency Report*, *supra* note 27 at 8.

[43] Wright, *supra* note 4 at 42.

[44] *Ibid*.

[45] *The First Galileo Satellites: Galileo in Orbit Validation Element (GIOVE)*, (European Space Agency, 2005) at 5, online: <http://www.esa.int/esapub/br/br251/br251.pdf>.

[46] Wright, *supra* note 4 at 42. The orbit used by GPS is also known as semi-synchronous orbit.

(GTO). This orbit is used by the upper stages of rockets to deliver satellites to GEO.[47] Due to its velocity after releasing the satellites, the remaining portion of the rocket is stranded in an elliptical orbit with a low (perigee) of about 300 kilometers and a high (apogee) at or near the GEO orbit altitude, posing a collision risk with functioning GEO satellites.[48] The average lifetime for debris in GTO can vary from a few years to one hundred years.[49]

The second orbit is called a Molniya orbit, which is sometimes known as a highly elliptical orbit (HEO).[50] This orbit is designed in such a way that the satellites placed there orbit Earth once every 12 hours and spend most of their time over the northern hemisphere.[51] On each orbit, the satellite's altitude goes from a low altitude of about 1,000 kilometers to a high of about 40,000 kilometers.[52] The satellites placed here are used for communications in and around Russia as well as for early warning satellites that monitor Russian and US missile launches.[53] The third orbit is known as a Tundra orbit. The Tundra orbit is likewise used over the northern hemisphere, primarily for military purposes. Satellites in this orientation have an orbital period of 24 hours and range from a low altitude of 18,000 kilometers to a high of 54,000 kilometers.[54]

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[47] Baker, *Space Debris*, *supra* note 41 at 24.
[48] *Ibid*.
[49] National Research Council Committee on Space Debris, *Orbital Debris: A Technical Assessment* (Washington: National Academy Press, 1995) [*Technical Assessment*] at 147.
[50] Wright, *supra* note 4 at 42-43.
[51] *Ibid*. at 43.
[52] *Ibid*.
[53] *Ibid*.
[54] *Ibid*.

5. Lagrange Points

Lagrange points[55] are five special solar (as opposed to Earth) orbits in which satellites remain in a fixed position relative to Earth because of the interaction between the Sun's gravity and that of Earth.[56] Although this paper focuses on Earth orbits, Lagrange points are mentioned here because they are very small areas, finite in number, with the potential for crowding. Two of the points are useful for astronomical observations.[57] Spacecraft located at the Lagrange points are relatively stable and need little fuel for station-keeping.[58] This also means that any debris around Lagrange points will remain in the area for long periods of time.

C. Sources of Artificial Orbital Debris

Before analyzing where orbital debris comes from, it would be useful to know what the accepted definition of orbital debris is. However, there is no universally accepted definition.[59] Thus, the search for a definition should begin with a practical approach and the process of elimination. The primary concern with orbital debris is that it pollutes the outer space environment by making satellites more susceptible to damage from collision. Thus, everything orbiting around Earth poses some level of risk to every other object in orbit. The issue is which of those objects should be classified as orbital debris. At the outset, objects and particles that occur naturally in space, even though they

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[55] They are also known as Lagrangian points, L-points, or libration points.

[56] *Ibid*. at 45.

[57] L_1 is located approximately 1,500,000 kilometers from Earth on a line directly between the Sun and Earth and is used for missions studying the Sun. L_2 is located on the same line, but on the side of Earth away from the Sun an equal distance away and is the planned location of the successor to the Hubble Space Telescope. *Ibid*. The remaining three Lagrange points are not particularly useful at this time. *Ibid*.

[58] *Ibid*. at 46.

[59] See Part IV.A below.

do pose some risk to satellites, should be excluded from the definition of orbital debris because humans have no way to control the creation, movement, or removal of those types of objects in space. Next, functioning satellites capable of maneuvering should be excluded as no one would consider those to be debris.[60]

What about satellites that are capable of maneuvering but through some malfunction have lost the ability to perform their mission? At some point after losing mission functionality, a satellite operator would most likely abandon efforts to use the satellite and the satellite could clearly be defined as debris.[61] What about satellites that are no longer capable of maneuvering but are still able to accomplish some or all of their missions and are still being used by their operators? What about objects that were never able to maneuver in the first place and may or may not have continue to serve some useful purpose?[62] The answer to these questions depends on one's perspective since, as it is said, "one person's trash is another person's treasure." Nevertheless, to facilitate the discussion in this paper, it seems appropriate to include in the category of debris any object not capable of being maneuvered or no longer of use to its operator. Combining these criteria results in the following definition, which has gained some acceptance in the international community: "any man-made earth-orbiting object which is non-functional

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[60] Debris can be defined as the remains of something broken down, destroyed, or discarded. *Merriam-Webster Online Dictionary*, *s.v.* "debris," online: <http://www.merriam-webster.com/dictionary/debris>.

[61] Nevertheless, the operator should attempt to move the satellite to an appropriate disposal orbit to reduce the risk to other operational satellites. For a discussion of disposal orbits, see Part IV.D below.

[62] For example, in 1961, the US, in an effort called Project West Ford, launched millions of short, thin copper wires into space for the purpose of creating a ring around Earth that could aid communications by dispersing radio waves. Daria Diaz, "Trashing the Final Frontier: An Examination of Space Debris from a Legal Perspective" (1993) 6 Tul. Envtl. L.J. 369 at 370 note 4; NASA National Space Science Data Center, *Project West Ford*, online: <http://nssdc.gsfc.nasa.gov/database/MasterCatalog?sc=1963-014A&ex=1>. They were placed into orbit at about 3,650 kilometers and individual copper wires returned to Earth in a few years, but the majority of them clumped together, delaying reentry. As of 1987, 60 out of 102 identifiable clumps remained in orbit (Diaz at 370 note 4).

with no reasonable expectation of assuming or resuming its intended function or any other function for which it is or can be expected to be authorized."[63]

Orbital debris comes from many sources, but these can be broadly categorized into four types: (1) inactive payloads (2) operational debris, (3) fragmentation debris, and (4) microparticulate matter.[64] As of 2006, the US Space Surveillance Network (SSN)[65] had cataloged almost 10,000 pieces of orbital debris.[66]

1. Inactive Payloads

Inactive payloads are primarily made up of satellites which have run out of fuel for station-keeping operations or have malfunctioned and are no longer able to maneuver. The payload is the *raison d'etre* for the launch, as distinguished from the rocket used to launch the payload into orbit. The SSN currently tracks almost 3,000 objects in this category, only a few hundred of which are active satellites and the remainder is debris.[67]

2. Operational Debris

Operational debris includes any intact object or component part that was launched or released into space during normal operations. The largest single category of this type of debris is intact rocket bodies that remain in orbit after launching a satellite. The SSN

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[63] David Tan, "Towards a New Regime for the Protection of Outer Space as the 'Province of All Mankind'" (2000) 25 Yale J. Int'l L. 145 at 151 note 21 (citing definition proposed by the International Academy of Astronautics).

[64] Baker, *Space Debris*, *supra* note 41 at 3-9.

[65] See *infra* notes 87-116 and accompanying text for additional information about the SSN.

[66] NASA Orbital Debris Program Office, "Monthly Number of Cataloged Objects in Earth Orbit by Object Type" (2006) 10:2 *Orbital Debris Quarterly News* 10, online: <http://www.orbitaldebris.jsc.nasa.gov/newsletter/pdfs/ODQNv10i2.pdf> [Cataloged Objects]. This publication also breaks down debris generated by each State. The US is responsible for approximately 42 percent of the total amount of debris and the Russian Federation another 43 percent. No other single State accounts for more than four percent of the total debris. *Ibid*. at 9.

[67] *Ibid*. at 10. There is no official source for the number of active satellites. One organization does maintain a list of satellites considered to be the only ones that are currently operational. That database currently contains 814 satellites. Union of Concerned Scientists, *UCS Satellite Database* (2006), online: <http://www.ucsusa.org/global_security/space_weapons/satellite_database.html>.

is currently tracking approximately 2,600 rocket bodies that are still in orbit around Earth.[68] An additional 2,400 miscellaneous operational debris objects are also being tracked.[69] Any number of things could fall into this category, including rocket nose cones, payload separation hardware, bolts, straps, and fuel tanks, all of which can occur in the normal process of launching a satellite into orbit.[70] A number of more unusual operational objects have also orbited Earth for various periods of time.[71]

3. Fragmentation Debris

Fragmentation debris is created when a space object breaks apart.[72] This type of debris can be created through explosions, collisions, deterioration, or any other means.[73] The SSN tracks approximately 3,600 pieces of fragmentation-type debris—the largest category of trackable debris.[74] Explosions are responsible for most of this type of debris. For example, between 1957 and 1999, 57 rocket upper stages created fragmentation debris because the residual propellant in the upper stage exploded. These explosions

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[68] *Ibid*.

[69] *Ibid*.

[70] Baker, *Space Debris*, *supra* note 41 at 4.

[71] Examples of unusual objects include a camera, sewage from the space shuttle, an astronaut's glove, and bags of trash tossed out of both US and USSR manned spacecraft. *Ibid*. More recently, in February 2006, an old Russian space suit stuffed with communications gear was thrown out of the International Space Station as a radio communications experiment for children. Robert Z. Pearlman, "Orlan Overboard: The Suit Behind the Sat" *Space.com* (3 February 2006), online: <http://www.space.com/news/cs_060203_suitsat_stats.html>. The suit was expected to burn up in Earth's atmosphere within about six weeks. *Ibid*. Urns carrying cremated human remains are also in orbit around Earth. Mahulena Hofmann, "Space Cemeteries—A Challenge for the Legal Regime of Outer Space" (2001) *Proceedings of the Forty-third Colloquium on the Law of Outer Space* 380.

[72] Initially the debris will form a loose cloud of particles around the object. Over time, the cloud loses form as the particles move around Earth, each affected in their own way by gravity and atmospheric drag. K.D. Bunte & G. Drolshagen, "Detection and Simulation of Debris Cloud Impacts" in Dansey, *supra* note 13 at 201. Debris clouds in GEO evolve differently than those in LEO. M.A. Smirnov & E.D. Kuznetsov, "Dynamical Evolution of a Cloud of Fragments After a Destruction Event in GEO" in Dansey, *supra* note 13 at 261.

[73] Baker, *Space Debris*, *supra* note 41 at 4.

[74] Cataloged Objects, *supra* note 66 at 10.

account for 30 percent of all the cataloged debris.[75] A large percentage of this debris came from explosions of the second stage of US Delta rockets.[76] Altogether there have been over 170 recorded break-ups.[77]

Some explosions have been caused intentionally. The USSR intentionally destroyed several reconnaissance satellites to prevent their recovery by other States.[78] The US tested an air launched anti-satellite weapon in 1985 that produced 230 pieces of trackable debris, and in 1986, intentionally caused two US satellites to collide, producing hundreds more pieces of detectable debris.[79] The US is planning a missile defense system which, if used, will cause a collision in the upper reaches of Earth's atmosphere that will likely result in orbital debris.[80]

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[75] Inter-Agency Debris Coordination Committee, "Activities and Views on Reducing Space Debris from Launch Vehicles" (Presentation to the 38th Session of the Scientific and Technical Subcommittee of the Committee on the Peaceful Uses of Outer Space, February 2001) at 7-8, online: <http://www.iadc-online.org/docs_pub/IADC_UN_Presentation_Feb01.pdf>. Explosions from these so-called non-passivated rockets can occur anytime from a few hours after launch to a quarter of a century later. *Ibid*.

[76] Baker, *Space Debris*, *supra* note 41 at 6. Between 1973 and 1981, seven Delta second stages exploded. Nicholas L. Johnson, "The Historical Effectiveness of Space Debris Mitigation Measures" (Paper presented to the 2005 International Astronautical Congress at Fukuoka, Japan, October 2005) published in 11 *International Space Review* (December 2005) [Johnson, "Historical Effectiveness"] 6 at 9, online: <http://www.satellite-evolution.com/portal/Athletic_page5_files/ISR/ISR%20Issue%2011.pdf>.

[77] National Aeronautics and Space Administration, *History of On-Orbit Satellite Fragmentations*, 13th ed. (Houston, Texas: NASA, 2004) [NASA, *History of Fragmentations*] at 7, online: <http://www.orbitaldebris.jsc.nasa.gov/library/SatelliteFragHistory/13thEditionofBreakupBook.pdf>.

[78] Baker, *Space Debris*, *supra* note 41 at 5.

[79] Nicholas L. Johnson & Darren S. McKnight, *Artificial Space Debris* (Malabar, FL: Orbit Book Company, 1987) [Johnson, *Space Debris*] at 15. The satellite collision intentionally occurred in a low altitude, so all known debris would naturally reenter Earth's atmosphere within a year. *Ibid*. The only other known intentional breakup caused by the US occurred in 1966 during an engineering test of a rocket upper stage. The debris decayed within 17 days. *Ibid*. at 16.

[80] Missile Defense Agency, *Draft Programmatic Environmental Impact Statement for Ballistic Missile Defense System* (1 September 2004) at ES-32 to 33, online: <http://www.mda.mil/mdalink/pdf/peisvol1.pdf>. Some commentators assert the Missile Defense Agency understates the amount of orbital debris that could be created by the planned system. See Steven A. Mirmina, "The Ballistic Missile Defense System and Its Effects on the Outer Space Environment" (2005) 31:2 J. Sp. L. 287, 299-302. A successful test of the system was conducted on 22 June 2006 in which the system destroyed a target more than 160 kilometers above Earth. Missile Defense Agency, News Release, "Missile Defense Test Results in Successful 'Hit To Kill' Intercept"

Collisions are another, albeit less common, source of fragmentation debris. Debris of this type may result from collisions between space object and either natural or artificial orbital debris. There have been documented cases of debris collisions, which in turn created more new debris.[81] Finally, debris can be created as the result of the gradual disintegration of the surfaces on a satellite due to exposure to the space environment.[82] For example, paint can deteriorate quite rapidly and although each individual paint fleck's orbit decays rapidly, the cumulative effect of many paint flecks creates a significant problem.[83]

4. Microparticulate Matter

This final category of debris, as the name implies, is very small. Mostly it is composed of particles and gases that make up the propellant of a satellite that are not completely consumed during the thrusting process.[84] Of course, collisions, explosions, and deterioration of larger debris can also create micro particles.

D. Calculating the Risks of Orbital Debris

The volume of space in which satellites operate is enormous. For example, the volume of LEO is more than 177 times larger than the volume of airspace typically used by commercial airliners.[85] It seems improbable that in such an enormous area, orbital

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06-NEWS-0018 (22 June 2006), online: <http://www.mda.mil/mdalink/pdf/06news0018.pdf>. The amount of orbital debris created through this test and how long it will last is currently unknown.

[81] See Part II.D.4 below.

[82] *Interagency Report*, *supra* note 27 at 13.

[83] *Technical Assessment*, *supra* note 49 at 26-7.

[84] Baker, *Space Debris*, *supra* note 41 at 8-9; *Technical Assessment*, *supra* note 49 at 75.

[85]

$$Ratio = \frac{4/3\pi(r+1500)^3 - 4/3\pi(r+100)^3 \quad \text{[Volume of LEO]}}{4/3\pi(r+10)^3 - 4/3\pi(r)^3 \quad \text{[Volume of Airspace]}}$$

debris would be a hazard to current and future operations in space. Although the risk is small, it cannot be ignored and steps must be taken to prevent further accumulation of debris, or the risk will increase. Furthermore, even though the risk is small, objects do collide in space and both manned and unmanned satellites have maneuvered in orbit to avoid close encounters with known debris.[86] Assessing the level of risk and knowing when and how to maneuver satellites to lower the risk of collision is a complex and imprecise endeavor.

1. Tracking Orbital Debris

The fundamental challenge in understanding the dangers of orbital debris—and thus, being able to mitigate those dangers—is to know where the debris is. This is a three-part problem. First, the debris has to be tracked. Second, the data collected has to be made available. Third, there needs to be a practical method of turning the data into a useful predictive tool for satellite operators.

a) Locating and Tracking Debris

The only comprehensive debris monitoring system is the SSN.[87] The system was originally designed to detect objects of military significance, but it is capable of performing the task of monitoring some other types of space objects, with significant limitations.[88] The SSN consists of approximately 30 radar and optical sensors located

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For this calculation, the lower and upper limits of LEO were assumed to be 100 and 1,500 kilometers, respectively, commercial airliners were assumed to fly up to 10 kilometers above Earth, and the average radius of Earth was assumed to be 6,371 kilometers.

[86] See *infra* note 139 and accompanying text.

[87] Space Security.org, *Space Security Index 2004* (Toronto: Northview Press, 2005) at 3, reprinted in 30:2 Ann. Air & Sp. L. 273, online: <http://www.spacesecurity.org/SSI2004.pdf>.

[88] *Technical Assessment*, *supra* note 49 at 32. An example of a limitation is the SSN's inability to monitor many objects in low-inclination orbits due to the lack of sensors in low latitudes (since sensors there would not help defend against a threat from the former Soviet Union). *Ibid*. at 35.

throughout the world.[89] The sensors were mostly built during the 1960s through the 1980s.[90] The SSN can collect data about objects' altitude, orbit, size, and composition.[91] The capabilities of the network are limited by the debris' size and altitude, however.

Historically in LEO, the SSN could not detect or track objects smaller than 10 centimeters, and only objects 30 centimeters and larger can be continuously tracked.[92] Most of the data and published reports are based on these figures. In March 2003, the sensitivity of the SSN was improved so that objects as small as five centimeters in LEO in medium to high inclinations can be tracked.[93] As altitude increases, the ability of the SSN's current sensors to detect small objects decreases. Objects in orbits of 5,000 kilometers altitude must be at least one meter in size to be tracked by the network.[94] Objects in GEO are primarily located through optical instruments (as opposed to radar) and also need to be at least one meter across to be tracked.[95] The current number of cataloged objects is about 10,000 and increasing.[96] In addition to cataloged objects, approximately 2,000 other objects are trackable but have not been added to the SSN

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[89] United States General Accounting Office, Report to Congressional Requestors, *Space Surveillance: DoD and NASA Need Consolidated Requirements and a Coordinated Plan* (1997), online: <http://www.gao.gov/archive/1998/ns98042.pdf> at 26.

[90] *Ibid*. at 11.

[91] *Ibid*. at 26.

[92] *Ibid*. at 11.

[93] Nicholas L. Johnson, "Orbital Debris Research in the U.S." in Dansey, *supra* note 13, 5 at 6 [Johnson, "Research in the U.S."]. Other radars allow the detection (but not tracking) of debris as small as 0.2 centimeters in LEO. *Ibid*.

[94] *Technical Assessment*, *supra* note 49 at 34-35.

[95] *Ibid*. Objects as small as 10 centimeters can be located in GEO but tracking objects that small is difficult and time consuming, thus they are not usually added to the SSN catalog. See Toshifumi Yanagisawa, Atushi Nakajiama, & Hirohisa Kurosaki, "Detection of Small GEO Debris Using Automatic Detection Algorithm" in Dansey, *supra* note 13, 147 at 151-52; Rüdiger Jehn, Vladimir Agapov, & Cristina Hernández, "End-of-Life Disposal of Geostationary Satellites" in Dansey, *supra* note 13, 373 at 377. The number of 10 centimeter sized objects in GEO is estimated at more than 2,000 (Jehn, *supra* at 377).

[96] Cataloged Objects, *supra* note 66.

catalog because of delays in completing the detailed analysis required before an object can be cataloged.[97] Upgrades to the SSN surveillance capability are currently in progress.[98]

Other States have debris tracking capabilities, but their programs are not as robust as that of the US. For example, the Russian Federation, Japan, the United Kingdom, France, and Germany all contribute to the knowledge of orbital debris through observation of the space environment.[99] The Russian Federation has approximately 22 telescopes and radars used for orbital debris detection.[100] Japan also has telescopes and a radar used to observe orbital debris.[101] Various States of the European Space Agency (ESA) also make several of their telescopes and radars available for orbital debris research.[102] The ESA has started feasibility studies for developing its own European Space Surveillance System which would have similar capabilities to the SSN.[103] Additionally, the ESA has a number of debris tracking systems that can be used to augment information provided by the SSN. For example, in 2005 the ESA began

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[97] Johnson, "Historical Effectiveness," *supra* note 76 at 9.

[98] Planned for the near future are a new radar and telescope which will be used to increase the SSN catalog of debris in low inclination orbits. Johnson, "Research in the U.S.," *supra* note 93 at 9.

[99] *National Research on Space Debris, Safety of Space Objects with Nuclear Power Sources on Board and Problems Relating to Their Collision with Space Debris*, UN COPUOS, UN Doc. A/AC.105/817, 2003 [*National Research* December 2003] at 11 (Great Britain); *National Research on Space Debris, Safety of Space Objects with Nuclear Power Sources on Board and Problems Relating to Their Collision with Space Debris*, UN COPUOS, UN Doc. A/AC.105/770/Add.1, 2002 [*National Research* February 2002] at 3-4 (Japan); *National Report on Space Debris Research in theRussian Federation in 2002*, UN COPUOS, UN Doc. A/AC.105/C.1/L.267, 2003 [*Research in Russian Federation*] at 2 (Russian Federation); *Technical Assessment*, *supra* note 49 at 32 (Russian Federation); UN, *Technical Report on Space Debris* (New York: UN, 1999) at 5-8 (also available as UN Doc. A/AC.105/720) (all).

[100] Sergey Kulik, "The Russian Federation Space Plan 2006-2015 and Activities in Space Debris Problems" in Dansey, *supra* note 13, 11 at 14.

[101] Takashi Nakajima, "Debris Research Activities in Japan" in Dansey, *supra* note 13, 17 at 17-19.

[102] H. Klinkrad *et al*., "Space Debris Activities in Europe" in Dansey, *supra* note 13, 25 at 26.

[103] *Ibid*.; T. Donath *et al*., "Proposal for a European Space Surveillance System" in Dansey, *supra* note 13, 31.

using European tracking services to independently confirm the orbits of debris in the SSN catalog that are at high risk for colliding with ESA satellites.[104] The information available from the European network has a smaller margin of error than data derived from the SSN's catalog.[105]

b) Availability of Data

To be useful, the information obtained through tracking efforts needs to be disseminated to all satellite operators, including nongovernmental entities. If a satellite operator knows that a particular object in space poses a collision risk to a satellite, the operator can maneuver the satellite to avoid the debris. Since collisions in space increase the amount of debris, it is in the interest of all States to ensure operators have access to this data. Historically, the data from the SSN has been made available through a National Aeronautics and Space Administration (NASA) web page.[106] This changed in 2004, however, as a result of the National Defense Authorization Act (NDAA) for Fiscal Year 2004.[107]

The 2004 NDAA created a three-year pilot program for the Department of Defense (DoD) to provide space surveillance data to any foreign or domestic governmental or commercial entity so long as it is consistent with national security.[108] As a result, NASA stopped providing tracking data in 2005. In order to receive SSN

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[104] H. Klinkrad, J.R. Alarcón, & N. Sanchez, "Collision Avoidance for Operational ESA Satellites," in Dansey, *supra* note 13, 509 at 514 [Klinkrad, "Collision Avoidance"].

[105] *Ibid*.

[106] T.S. Kelso & S. Alfano, "Satellite Orbital Conjunction Reports Assessing Threatening Encounters in Space (SOCRATES)" (Paper presented to the 15th AAS/AAIS Space Flight Mechanics Conference at Copper Mountain, Colorado, January 2005) at 3, online: <http://www.centerforspace.com/downloads/files/pubs/AAS_05-124.pdf>. Data from the Russian space surveillance database has not been easily available to the public. Space Security.org, *supra* note 87 at 18.

[107] Pub. L. No. 108-136, § 2274, 117 Stat. 1565-67 (2003) [2004 NDAA].

[108] *Ibid*.

tracking data, entities have to agree to pay any reasonable charges set by the DoD and not to further distribute the data to other users.[109] These potential restrictions initially caused some concern among scientists and satellite operators.[110] These concerns, however, ultimately proved unfounded as the DoD continued providing the same data as NASA,[111] the DoD has never charged a fee for access to the data, and the data is being freely redistributed to anyone with internet access.[112] For both the former NASA public database and the new DoD public database, the DoD has withheld information about certain classified US Government satellites and the rockets that launched them for national security reasons.[113] What happens in 2007 after the three year pilot program ends is still to be determined. Of course, for the reasons expressed above, it is in the best interest of not only the US but also the rest of the world for this data to be made available.

c) Making Data Useful

Satellite operators need a practical method of using the available data. Presently, there is only one software tool available that uses current data from the SSN[114] from all known orbital debris and compares it to all functioning satellites. The tool is known as

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[109] *Ibid*.

[110] Kelso, *supra* note 106 at 10; Space Security,org, *supra* note 87 at 18.

[111] The data is available online after establishing an account at <http://www.space-track.org>.

[112] The data is being redistributed by CelesTrak online: <http://www.celestrak.com>. The operators of this website received DoD approval to redistribute the space surveillance data in March 2005 and again in March 2006. CelesTrak, *Important Notice*, online: <http://www.celestrak.com/NORAD/elements/notice.asp>. The DoD web page is an improvement over the NASA webpage in that there are no longer restrictions on the amount of data that can be downloaded at one time.

[113] Kelso, *supra* note 106 at 3.

[114] Data more than a few days old is substantially less accurate. Data more than a month old is useless. *Ibid*. at 6.

SOCRATES and is available free of charge on the CelesTrak webpage.[115] Twice a day, the program compares satellites against all known debris and prepares a "Top 10 List" of satellites that are at the highest risk of being hit by another known space object. Satellite operators can use this information to maneuver functioning satellites, if necessary, to avoid collisions. As part of the three year DoD pilot project, the Air Force intends to offer a similar fee-based service with improved functionality over the SOCRATES program, although this is not yet available.[116]

2. Debris Models

Small debris, not contained in the SSN catalog, poses significant risks to satellites. The size of a piece of debris roughly equates to the risk the debris poses if it strikes another object. For purposes of small debris analysis, sizes can be divided into three categories: debris larger than one centimeter, debris between .01 to one centimeters in size, and debris smaller than .01 centimeters.[117] Debris smaller than .01 centimeters will typically only cause surface pitting and erosion, which over time may have significant consequences, but no individual impact with debris that small will cause noteworthy damage.[118] Debris between .01 centimeters up to about one centimeter in size can, depending on the structure of the satellite and where the debris hits, cause significant damage. However, satellites can, with existing technology, employ shielding

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[115] CelesTrak Socrates, online: <http://www.celestrak.com/SOCRATES>. Other tools are available, but do not provide worldwide support for all satellite operators. For example, the European Space Agency uses similar software to calculate collision probabilities for its own satellites. See J.R. Alarcón *et al*., "Independent Orbit Determination for Collision Avoidance" in Dansey, *supra* note 13, 331.

[116] United States Air Force, *Commercial and Foreign Entities (CFE) Support Pilot Program* Fact Sheet, online: <http://www.celestrak.com/NORAD/elements/notices/CFE_Fact_Sheet_v4.pdf>. In addition to assessment of collision probabilities, the Air Force intends to provide analysis of collision risk for planned maneuvers, support for launches, and support for planned de-orbit procedures. *Ibid*.

[117] *Interagency Report*, *supra* note 27 at 8.

[118] *Ibid*.

that protects from debris up to about 1.2 centimeters.[119] Debris larger than that will likely cause catastrophic damage to any satellite it strikes.

Because small debris cannot be tracked with current technology but poses substantial risks to satellites, a number of computer models have been developed and scientific experiments designed to estimate the quantity, type, and location of small orbital debris.[120] Estimates of debris smaller than .01 centimeters are many trillions of particles and estimates for the number of pieces of between .01 centimeters to 10 centimeters in size are in the tens of millions.[121] These estimates are important for satellite designers, operators, and for everyone interested in the health of the space environment as they play important roles in satellite safety and in ascertaining costs, both economic and political, of projected space activities.[122]

3. Risk Variables

The calculation of the level of risk to any particular satellite is not precise; it is just a probability. A number of constantly changing factors affect the level of risk. The likelihood of collision is primarily a function of the satellite's size, orbital altitude and inclination, and anticipated lifetime of the satellite.[123] The larger its size (cross-sectional area) and the longer it will stay in orbit, the greater the chance that a satellite will collide with orbital debris. The orbital altitude is significant because the amount of debris varies

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[119] *Ibid*.

[120] *Ibid*. at 16. Different models serve different functions. For example, an environment model characterizes the existing orbital debris environment; a traffic model estimates the debris resulting from future launches and accidental explosions; a breakup model estimates the quantity, size, and velocities of fragments following an explosion or collision; and a propagation model estimates how debris orbits change over long periods of time. *Ibid*. at 33. Descriptions of various models can be found in *Technical Report on Space Debris*, *supra* note 99 at 19-26.

[121] *Technical Assessment*, *supra* note 49 at 64. These estimates apply only to LEO. There is insufficient data to estimate the quantity of small debris outside LEO. *Ibid*.

[122] Baker, *Space Debris*, *supra* note 41 at 32; Johnson, *Space Debris*, *supra* note 79 at 86.

[123] *Interagency Report*, *supra* note 27 at 19.

greatly from one orbital region to another.[124] LEO has the most trackable debris, more than 70 percent, of the total, followed by GEO and GTO, which combined represent about 15 percent of the total.[125] The consequences of orbital debris impacting another object are related to yet another set of variables: the size, mass, and velocity of the debris; the angle at which it strikes the satellite; and the configuration, composition, and location of components on the satellite impacted by the debris.[126]

Given all these uncertainties, it is impossible to truly generalize the level of risk to a particular satellite. Too many variables are involved to make such generalizations. However, in order to provide some tangible probabilities to these concepts, rough estimations of the collision risk of a "typical" small LEO satellite with a lifetime of 10 years have been calculated. Chances of collision with an object larger than one centimeter are between one in 100 to one in 1,000 over the lifetime of the satellite.[127] The satellite will probably collide with about one piece of debris between .01 centimeters and one centimeter in size during its 10-year life.[128] Finally, it is estimated that this typical satellite will be impacted by 100 to 1,000 particles smaller than .01 centimeters.[129] Because the small debris population in GEO is unknown, estimates for collision

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[124] *Technical Assessment, supra* note 49 at 79. To a lesser extent, the inclination also affects the amount of orbital debris. *Ibid.* at 79, 82. Within the GEO, the longitude of the satellite is also a factor, since satellites tend to cluster in useful longitudes. Some GEO satellites experience up to 100 times the risk of an average GEO satellite because of their presence in a crowded location. Johnson, *Space Debris, supra* note 79 at 77-78.

[125] *Interagency Report*, *supra* note 27 at 11.

[126] *Technical Assessment*, *supra* note 49 at 88. Velocity varies with orbital altitude and the inclination. *Ibid*. at 89. The highest velocities, and therefore increased potential for damage, occur in LEO, and the lowest velocities are in GEO. See *supra* note 5; *Technical Assessment*, *supra* note 49 at 89-90.

[127] *Ibid*. at 81. To put this in perspective, consider that a person 25 years old living in the US has only about a one in 10,000 chance of dying before the age of 35. Department of Health and Human Services, 54:14 *National Vital Statistics Reports* 8 (Washington, DC 2006), online: <http://www.cdc.gov/nchs/data/nvsr/nvsr54/nvsr54_14.pdf>.

[128] *Technical Assessment*, *supra* note 49 at 81.

[129] *Ibid*. For other LEO estimates, see *Technical Report on Space Debris*, *supra* note 99 at 28.

probabilities in GEO among untrackable objects are virtually impossible to calculate, but are much lower than the probabilities for LEO because the density of space objects and debris in GEO is 100 to 1,000 times lower than in LEO.[130] For trackable debris in GEO, the annual probability for a collision for any individual object is one in 100,000.[131] Nevertheless, collisions in GEO are not without precedent.[132]

4. Historical Examples

Although the current risk to any one satellite should certainly be characterized as low, orbital debris can and does damage satellites. Every week, hundreds of cataloged objects pass within one kilometer of each other.[133] Although this may seem to be a large distance of separation leaving no cause for concern, the SSN catalog has a sufficiently high margin of error such that objects passing within this range are at serious risk for collision. The Space Shuttle is often moved if a known object is expected to pass within two kilometers.[134]

There have been three confirmed cases of cataloged artificial debris colliding with other cataloged objects.[135] In 1991, a non-functional Russian navigation satellite in LEO collided with a piece of debris that had previously detached from another Russian

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[130] *Technical Assessment*, *supra* note 49 at 84. The density is lower because the volume of space in GEO is larger than the volume in LEO and there are fewer artificial objects in GEO than in LEO.

[131] *Technical Report on Space Debris*, *supra* note 99 at 28.

[132] In March 2006, a Russian telecommunications satellite in GEO failed due to a collision with an unknown object. Peter de Selding, "'Sudden External Impact' Cripples Russian Satellite" *Space.com* (30 March 2006), online: <http://www.space.com/missionlaunches/060330_am11_satfail.html>.

[133] Kelso, *supra* note 106 at 2-3.

[134] *Technical Report on Space Debris*, *supra* note 99 at 36.

[135] NASA Orbital Debris Program Office, "Accidental Collisions of Cataloged Satellites Identified" (2005) 9:2 *Orbital Debris Quarterly News* 1, online: <http://www.orbitaldebris.jsc.nasa.gov/newsletter/pdfs/ODQNv9i2.pdf>. Although these three are the only confirmed cases, there is some evidence that the earliest collision with orbital debris occurred to a Soviet navigation satellite in 1981. Johnson, *Space Debris*, *supra* note 79 at 91. This list excludes intentional collisions, such as those listed in notes 79-80, *supra*.

satellite. The impact created many new pieces of debris, only two of which were trackable by the SSN.[136] In 1996, a functional French spacecraft was hit by a fragment of a French rocket stage that had previously exploded.[137] Finally, in 2005, a US rocket and a fragment of a previously exploded Chinese rocket collided, creating several new pieces of trackable debris.[138] Additionally, many manned and unmanned spacecraft have altered their orbits to avoid collisions with known orbital debris.[139]

Unlike with large debris, collisions between satellites and small, untrackable pieces of debris are common. One of the most cited examples of this type of impact comes from 1983 when a paint fleck smaller than .01 centimeters seriously damaged the window of a Space Shuttle orbiter.[140] Many other satellites that have returned to Earth have shown impacts from orbital debris upon examination.[141] Much of what is known about the types and quantities of small orbital debris in LEO comes from studies of those objects.[142]

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[136] *Ibid*. Although the event occurred in 1991, it was not identified until 2005 when SSN experts were examining historical data. *Ibid*.

[137] *Ibid*. at 1-2.

[138] *Ibid*. at 1.

[139] For example, Space Shuttle orbiters have maneuvered at least eight times. Peter T. Limperis, "Orbital Debris and the Spacefaring Nations: International Law Methods for Prevention and Reduction of Debris, and Liability Regimes for Damage Caused by Debris" (1998) 15 Ariz. J. Int'l & Comp. Law 319 at 325. For examples of unmanned spacecraft maneuvers, see NASA Orbital Debris Program Office, "Collision Avoidance Maneuver Performed by NASA's Terra Spacecraft" (2006) 10:1 *Orbital Debris Quarterly News* 1, online: <http://www.orbitaldebris.jsc.nasa.gov/newsletter/pdfs/ODQNv10i1.pdf>; Klinkrad, "Collision Avoidance," *supra* note 104 at 513 (five maneuvers for three spacecraft between 1996 and 2004).

[140] *Technical Assessment*, *supra* note 49 at 26-7.

[141] Examples of well-known spacecraft showing impacts include Apollo capsules, the Skylab and Mir space stations, and the Hubble Space Telescope. *Ibid*. at 45.

[142] *Ibid*.

5. Future Estimates

Estimates of the future levels of risk are even more speculative than estimates of current risk levels, but most show an alarming trend of increasing debris. A recent NASA study, published in January 2006, estimates the amount of debris 10 centimeters and larger in LEO will triple within 200 years, increasing the likelihood of debris collisions by a factor of 10.[143] The greatest concentration of orbital debris will be located in the regions 800-900 kilometers and 1400-1500 kilometers in altitude.[144] The study acknowledges it seriously underestimates the future risk as it assumes there will be no further launches into space.[145] For each of the past five years, there has been an average of 59 launches worldwide per year.[146] Considering that each of these launches produces multiple pieces of debris in addition to a functional satellite, the future risk in the NASA study is clearly understated.

The greatest fear of those who study the problem of orbital debris is the cascade-effect. If the cascade-effect begins, orbital debris would collide with other space objects, which in turn would create new debris that would cause even more collisions. In this way, orbital debris would become self-generating and could make certain regions of space completely unusable, even without new satellites being placed in those areas.[147] International efforts aimed at mitigating the creation of new debris have helped,[148] but will not alone solve the problem. That is why many authors are calling for increased

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143 J.C. Liou & N. L. Johnson, "Risks in Space from Orbiting Debris" (20 January 2006) 311 *Science* 340.
144 *Ibid*. at 341. The greatest concentrations presently exist in the same altitude bands.
145 *Ibid*.
146 Federal Aviation Administration, *Commercial Space Transportation: 2005 Year In Review* 13, online: <http://ast.faa.gov/files/pdf/2005_YIR_FAA_AST_0206.pdf> [FAA, *2005 Year in Review*].
147 Baker, *Space Debris*, *supra* note 41 at 13.
148 See below, Parts IV.C-IV.F

research efforts into technologies for remediation—removal of existing debris from space.[149] Unfortunately, remediation measures are currently economically or technologically unfeasible.[150]

E. Remediation of Orbital Debris

Only two types of operations to remove debris are under serious consideration by experts on orbital debris.[151] One involves sending a satellite to known debris and either capturing the debris or attaching a device (tether or engine) that would enable the debris to reenter Earth's atmosphere.[152] The primary problem with this concept is that the fuel expenditure to visit more than one piece of debris per launch is enormous. Even for debris at the same altitude, the visiting spacecraft will have to make changes to orbital inclination, a maneuver requiring substantial amounts of fuel. A secondary problem is managing the rendezvous automatically or remotely. The only successful on-orbit rendezvous to date have been accomplished via control by an astronaut,[153] something not possible for remediation of large quantities of orbital debris. A 2005 NASA test of a computer-controlled rendezvous, the first of its kind, ended in failure, illustrating the difficulties inherent in this type of activity.[154] The only other potential remediation measure involves using ground-based lasers to perturb the orbit of debris and cause it to

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[149] See *e.g.*, Liou, *supra* note 143 at 340-41.

[150] *Ibid*.

[151] In addition to the practical problems, it is questionable whether these technologies can legally be implemented, at least for debris created by a different launching State. See Part V.B.4 below.

[152] *Ibid*.

[153] National Aeronautics and Space Administration, *Getting Together, Space Style*, online: <http://www.nasa.gov/mission_pages/dart/rendezvous/rendezhistory.html>.

[154] National Aeronautics and Space Administration, *Overview of the DART Mishap Investigation Results* (15 May 2006), online: <http://www.nasa.gov/pdf/148072main_DART_mishap_overview.pdf>.

reenter Earth's atmosphere more quickly.[155] However, the tracking ability of the lasers, the ability to discriminate among active satellites and debris, and the high energy levels required to have any noticeable effects makes this proposal currently impractical.[156]

III. Consequences of Orbital Debris

An active satellite that collides with a large piece of debris will be destroyed. Small debris can completely disable or seriously degrade a satellite's performance, depending on what systems are affected. Sufficient quantities of even microparticulate matter can shorten a satellite's life by damaging its optical sensors or solar arrays. These are the direct, and therefore most obvious, consequences of orbital debris. But there are many other consequences that create significant and long-term technical, legal, political, and economic impacts, which are described in this Part.

A. Debris Avoidance

Since the location of some orbital debris is known, debris avoidance procedures can begin during the mission planning stage. For example, certain LEO altitudes are more congested than others.[157] If the satellite's mission will permit, its altitude could be increased or decreased to account for the orbital debris. If relocating to another orbit would decrease the satellite's ability to perform its mission, the operators would be reluctant to make those changes. If it is not possible to relocate the satellite to a different altitude, the operator will have to deal with the increased risk of high-traffic areas. Orbital debris can be a factor immediately prior to launch as well. Rockets have

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[155] Liou, *supra* note 143 at 341.
[156] *Ibid*.
[157] See *supra* note 144 and accompanying text.

windows of time during which they can be launched.[158] It is not uncommon for a few minutes of the window to be unavailable to avoid passing near known space objects.[159] Finally, once in orbit, satellites encountering known debris with sufficient warning may be able to maneuver to avoid the debris, however, satellites have limited quantities of fuel on board for maneuvering. Once that fuel is gone, satellites can no longer maneuver and in most cases, their useful life will end. Therefore maneuvering to avoid debris, though possible, shortens the life of satellite and is an important consequence of orbital debris.

B. Mass Penalty

Satellites can and should be protected from impacts of small particles through shielding. Satellites should also carry sufficient fuel or alternative means of maneuvering[160] to transfer them to a disposal orbit (or to return them to Earth) at the end of their useful life.[161] Although shielding and disposal orbit transfers are helpful steps in preventing the creation of new orbital debris, these mitigation measures also have several negative consequences to satellite operators, which can collectively be termed their "mass penalty." First, because shields and alternative propulsion methods add to the mass of a satellite, the amount of fuel the satellite can carry is reduced (because of the maximum

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[158] The amount of time available depends upon a number of factors, including the location of the satellite's final position.

[159] Gunnar Leinberg "Orbital Space Debris" (1989) 4 J.L. & Tech. 93 at 112.

[160] An example of this could be a tether. See Part VI.A.1 below.

[161] The fuel it takes to maneuver to a disposal orbit varies from satellite-to-satellite and from orbit-to-orbit. For purposes of illustration, a typical GEO satellite that needs to boost 300 kilometers above GEO will use approximately three months worth of station-keeping fuel. Nandasiri Jasentuliyana, "Space Debris and International Law" (1998) 26:2 J. Sp. L. 139 at 155 [Jasentuliyana, "Space Debris"]. The calculation of the amount of fuel needed is complicated by the fact that the margin of error for estimating the amount of fuel remaining on board a satellite is also about three months worth of fuel. V. Davidov, "Measures Undertaken by the Russian Federation for Mitigating Artificial Space Debris Pollution" in Dansey, *supra* note 13, 53 at 55.

amount of mass that a rocket can carry into orbit).[162] Second, once on orbit, the more mass a satellite has, the more fuel it takes to maneuver.[163] Therefore, a satellite with shielding or end-of-life disposal hardware will have a shorter life than an identical satellite without those mitigation measures. Finally, the cost to launch a satellite into orbit increases roughly proportionately with increases in mass.[164] Accordingly, a satellite with these mitigation measures will not only have a shorter lifespan, but it may also cost more to launch.

C. Environmental Consequences

As the amount of debris in a particular orbital area increases, so does the risk of placing a new satellite into that area. As the NASA study discussed in Part II.D.5 above demonstrated, certain areas of space that are already crowded with debris are particularly susceptible to the creation of new debris. If the feared cascade-effect begins for one of these areas, that area of space could become so dangerous that it would be unusable for hundreds or thousands of years. Even if an area of space is not so hazardous that it is unavailable, the risks of putting an operational satellite into that area will be very high. This could increase the costs by requiring more mitigation measures (mass penalty) or through increased insurance premiums.[165]

The study of astronomy is also negatively affected by large amounts of orbital debris. For example, debris already interferes with Earth-based astronomical

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[162] *Technical Report*, *supra* note 99 at 39. The expense of incorporating shields and other mitigation measures during the design phase of a satellite also reduces profits of commercial operators.
[163] Space Security.org, *supra* note 87 at 69-76.
[164] *Ibid*. at 69.
[165] See Part III.E below for a discussion of the insurance consequences of orbital debris.

observations and can either decrease the quality of, or completely negate, many hours of observations.[166]

D. Tracking

Maintaining an accurate and current catalog of orbital debris has its own costs. The instruments used to track the debris must be built and maintained; computer software must be written; and man-hours must be spent interpreting and applying the data. Although these costs are undoubtedly worth the effort because of the information made available through debris tracking systems, if debris did not present such a problem, the tracking costs could undoubtedly be lessened. In fact, tracking costs are likely to increase. More modern and sensitive tracking instruments will soon be needed to replace the ones that currently exist. Eventually, technology may permit the placement of tracking instruments in space, in which case the costs of tracking will also increase because of the costs of operating a space-based sensing satellite.

E. Insurance

Broadly, there are two types of insurance. The first type compensates a satellite owner or operator for the loss of a functional satellite. This type of insurance is available to cover different phases of a satellite's life, beginning with manufacturing and pre-launch.[167] The most commonly purchased types of insurance, however, cover the phases of launch, in-orbit commissioning, and in-orbit life.[168] In a typical policy, 25 percent of the premium covers the launch and 75 percent applies to the remainder of the satellite's

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[166] *Technical Report*, *supra* note 99 at 17; Perek, *Discussion Paper*, *supra* note 33 at 195.

[167] Federal Aviation Administration, *Quarterly Launch Report 2nd Quarter 2006* (Washington, DC 2006) at SR-3, online: <http://ast.faa.gov/pdf/rep_study/2Q2006_QLR.pdf>.

[168] *Ibid*.

operational life.[169] Many satellites undoubtedly fail for design or operational reasons that are unrelated to orbital debris. But it is equally clear that some satellites do collide with orbital debris. Therefore, this is something that insurance underwriters will eventually have to consider in setting insurance premiums for a satellite's operational phase.[170] The insurance market rapidly changes in response to launch successes and launch failures, which make up only one fourth of the premiums.[171] Similarly, as more collisions with debris are confirmed and reported (or as the orbital debris risk increases), insurance underwriters will undoubtedly pay attention to that trend and respond by increasing premiums or excluding from their policies damage caused by orbital debris.[172]

The second type of insurance provides compensation to third parties injured by launch operations. The US requires any person or entity that intends to conduct a space launch within US territory to obtain a license from the Department of Transportation.[173] As a condition of the license, the launch operator is required to maintain this type of third-party insurance.[174] Although the coverage is provided for the launch operator, the satellite operator must be named as an additional insured; thus it applies to any damage caused to third parties by either the rocket or the satellite.[175] In theory, this insurance

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[169] *Ibid*. at SR-4 to SR-5. The cost of insurance premiums varying depending on the level of risk associated with the launch vehicle and satellite, but generally a premium is between 15 and 20 percent of the total cost of the launch. *Ibid*. at SR-7.

[170] Christopher T. W. Kunstadter, "Insurance Aspects of Space Operations" in John A. Simpson, ed., *Preservation of Near-Earth Space for Future Generations* (New York: Cambridge University Press, 1994) 159 at 160.

[171] *Ibid*. at SR-4 to SR-7.

[172] The insurance industry has not yet been presented with a claim for damage resulting from orbital debris. Delbert D. Smith, "The Technical, Legal, and Business Risks of Orbital Debris" (1998) 6 N.Y.U. Envtl L. J. 50 at 64. For other possibilities concerning insurance against orbital debris, see *ibid*. at 64-66.

[173] 14 C.F.R. § 413.3. If the entity or person is a US citizen, the license requirement applies no matter where the launch will take place.

[174] 14 C.F.R. § 440.9.

[175] *Ibid*.

could cover damage caused by either the rocket or the satellite to other objects in space. In practice, however, the insurance coverage is only required to extend 30 days past the launch;[176] therefore, this type of insurance will probably not be affected by the quantity of orbital debris. Nor does it provide protection to the launch operator if its rocket body causes damage to a third party's satellite after the time period of coverage lapses.

F. International Conflict and the Law of War

Orbital debris has the potential to increase tension during times of international conflict.[177] Consider this scenario: State A and State B, both space-faring nations, are on the brink of war with each other. Unexpectedly, a sensitive and critical military reconnaissance, navigation, or communications satellite of State A stops working. The malfunction was caused by a small piece of orbital debris, but the government of State A is unaware of the cause. State A's government might legitimately think that State B was somehow involved in damaging the satellite,[178] but, lacking the capability to track orbital debris that size, no one will ever be able to prove or disprove that theory. The current orbital debris problem makes this scenario plausible. Of course, no one can know how a State would choose to respond to such a sequence of events, but States have gone to war over lesser matters.

Orbital debris also limits the possibilities for direct military attacks against satellites. In this case, the problem is not existing debris, but the need to avoid creating substantial amounts of new debris. Conventional kinetic weapons in space are not prohibited by international law (but nuclear weapons and other weapons of mass

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[176] 14 C.F.R. § 440.11. This type of coverage is available for satellite operators as well as launch operators, but it is purchased by satellite operators very infrequently. Kunstadter, *supra* note 170 at 161.

[177] Baker calls this possibility "misinterpretation." Baker, *Space Debris*, *supra* note 41 at 13-14.

[178] Especially if State B has relevant tracking data but refuses to share it.

destruction are prohibited).[179] Therefore, one State could lawfully launch a traditional military attack against the satellites of another State.[180] The most significant traditional rules of military warfare, specifically necessity, discrimination, proportionality, and humanity, still apply in space.[181] For the issue of creating debris in space, the two most important principles are discrimination and proportionality. The rule of discrimination requires that a military attacker distinguish between legitimate military objectives and non-combatants.[182] The rule of proportionality mandates that the force used be proportional to the objective; it requires a balancing between the potential damage to be caused against the military advantage that will be gained.[183]

Intentionally destroying a satellite has the potential to create enormous amounts of long-lasting orbital debris. Therefore, any military operation designed to destroy a satellite must be carefully planned to limit the amount of debris created and should only be undertaken after careful consideration of the principles of discrimination and proportionality. The risk from orbital debris is greatest in a traditional kinetic event (such as exploding a warhead in close proximity to a satellite or intentionally causing two satellites to collide). However, other ways of destroying a satellite that cause less debris are possible.[184] One such example is a space control parasitic attitude control system.

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[179] Rob Ramey, "Armed Conflict on the Final Frontier: The Law of War in Space" (2000) 48 A.F.L. Rev. 1 at 78-9.

[180] Such an attack would only be lawful if it were in self-defense or authorized by the United Nations. See *Charter of the United Nations* at art. 51.

[181] Ramey, *supra* note 179 at 34-5. Although these concepts developed for use on land, sea, and later air, they still apply to outer space. *Legality of the Threat or Use of Nuclear Weapons Case*, Advisory Opinion, [1996] I.C.J. Rep. 226 at 89; Ramey, *supra* note 179 at 123-30.

[182] Ramey, *supra* note 179 at 36-9.

[183] *Ibid*. at 39-40.

[184] Disabling a satellite without causing any debris is possible by jamming radio communication frequencies or destroying ground communications stations. These are not, however, permanent

This type of system works by attaching a maneuvering/thrusting device to the exterior of the target satellite and then thrusting in such a way that that parts of the satellite break off.[185] Once a few significant parts of the satellite have broken away, it would be permanently disabled, creating only a few pieces of debris, which would probably be large enough to be trackable.[186]

Nevertheless, military attacks against satellites present unique challenges. In a typical land, sea, or air military operation, the effects are usually localized. A military attack in space that creates orbital debris, on the other hand, has the potential to cause harm to the satellites of every State in the world, including those not a party to the conflict (neutrals). Additionally, depending on the size of the debris, people and property anywhere on Earth are at risk when the debris re-enters Earth's atmosphere.[187] For these reasons, the risk of creating orbital debris is a good reason to avoid using anti-satellite weapons.

G. Debris Re-entering Earth's Atmosphere

Orbital debris will eventually return to Earth. Some of it survives re-entry and can be hazardous to persons, animals, and property. There has been only one reported case of a person actually being hit by falling orbital debris; she was not injured.[188] An estimated 200 pieces of debris re-enter Earth's atmosphere every year, and there are

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solutions. If the attacking State desires to permanently destroy the satellite, some type of direct attack against the satellite (whether kinetic or not) will be required.

[185] Joseph T. Page II, "Stealing Zeus' Thunder: Physical Space-Control Advantages Against Hostile Satellites" (2006) 20:2 Air and Space Power Journal 26 at 29-31, online: <http://www.airpower.maxwell.af.mil/airchronicles/apj/apj06/sum06/sum06.html>.

[186] *Ibid*.

[187] The risk to persons on Earth is quite small, however. See Part III.G below.

[188] Mike Toner, "Final Frontier Littered with Junk" *Atlanta Journal and Constitution* (26 February 2006) 1A (LEXIS).

several dozen well-documented cases of large pieces of debris surviving re-entry.[189] Nevertheless, the risk of personal injury or property damage from falling orbital debris is still much smaller than the miniscule risk posed by the estimated 500 natural meteorites that hit Earth every year.[190] Unlike the many other consequences of orbital debris, this risk will not substantially increase with larger numbers of debris since most of the debris will always incinerate in the atmosphere. That is not true for one category of debris, however—radioactive debris. More radioactive debris in orbit means an increased risk to Earth's population.

From 1961 through 1988, the Soviet Union and the US launched into Earth orbit dozens of satellites with radioactive material on board.[191] Altogether there is about 1,500 kilograms of radioactive material still in orbit around Earth, most of it in LEO.[192] Although some of the power sources are relatively safe and pose little threat to Earth's environment,[193] others can have deadly consequences.[194]

For example, in 1978 the Soviet satellite Cosmos 954 reentered Earth's atmosphere and crashed into Canada. The satellite spread radioactive debris over a

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[189] *Ibid*.

[190] Johnson, *Space Debris*, *supra* note 79 at 67-8.

[191] Johnson, *Space Debris*, *supra* note 79 at 91-95; Nicholas L. Johnson, "A New Look at Nuclear Power Sources and Space Debris" in Dansey, *supra* note 13, 551 at 551-53 [Johnson, "Nuclear Power Sources"]. Since 1988, only satellites bound for other planets or deep space have used nuclear power sources, however, these pose no radiological threat to Earth. For example, the US has launched 25 satellites using radioisotope thermoelectric generators, including the Viking, Pioneer, Voyager, Ulysses, Galileo, and Cassini missions. United States Department of Energy, *Nuclear Power in Space* at 7, online: <http://www.ne.doe.gov/pdf/npspace.pdf>.

[192] Johnson, *Space Debris*, *supra* note 79 at 91-95. At least 8 radioisotope thermoelectric generators, 13 nuclear reactor fuel cores, and 32 nuclear reactors (one from the US and 31 from the Soviet Union) are still in LEO. Johnson, "Nuclear Power Sources," *supra* note 191 at 552. For explanations of the different types of nuclear materials used in space, see Joseph. J. MacAvoy, "Nuclear Space and the Earth Environment: The Benefits, Dangers, and Legality of Nuclear Power and Propulsion in Outer Space" (2004) 29 Wm. & Mary Envtl. L. & Pol'y Rev. 191 at 195-204.

[193] United States Department of Energy, *Space Radioisotopes Power Systems Safety* (2002), online: <http://www.ne.doe.gov/pdf/SRPS_safety.pdf>.

[194] MacAvoy, *supra* note 192 at 214-220.

sparsely populated 800 kilometer long area of the Northwest Territories.[195] Many of the pieces found during the subsequent recovery efforts were highly radioactive. Fortunately, testing of the surrounding areas revealed no radioactive contamination of the air, water, or food supplies.[196] In two other incidents in 1973 and 1983, similar Soviet Cosmos satellites returned to Earth leaving traces of radioactivity in the ocean and air.[197] In 1964, a US satellite scattered radioactive plutonium over South America.[198] Because of the concern about radioactive contamination of Earth from space, the United Nations acted in 1992 by creating the Principles Relevant to the Use of Nuclear Power Sources in Outer Space.[199]

IV. Existing Legal and Technical Orbital Debris Control Regimes

Current international and national laws and policies play important roles in limiting the creation of new orbital debris and in establishing liability for collisions caused by debris. The efforts of the US are highlighted since they are the most extensive and publicly available. However, since space law is inherently international in character, this Part begins with an overview of relevant treaties and customary international law.

A. International Space Law

The terms "space debris" and "orbital debris" are used extensively in the academic and scientific literature concerning the impact of man-made space objects upon the space environment. Those terms, however, are neither used nor defined in any of the

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[195] *Ibid*. at 213.
[196] *Ibid*.
[197] *Ibid*.
[198] Gerhard Reintanz, "Some Legal Remarks on Space Activities Which May Have Harmful Effects on the Environment" (1973) *Proceedings of the 15th Colloquium on the Law of Outer Space* 277.
[199] *Principles Relevant to the Use of Nuclear Power Sources in Outer Space*, GA Res. 47/68, UN GAOR, UN Doc. A/47/68, 1992 [*NPS Principles*]. For a discussion of the NPS Principles, see Part IV.G below.

treaties or United Nations resolutions that constitute the law of outer space. Therefore, in order to examine what existing international rules—if any—regulate orbital debris, a close look at each of the relevant instruments is necessary to see what impact they might have.[200] The rules can be broken down into two broad categories: those that assist in preventing the creation of debris and those that govern the consequences of debris. International law almost exclusively concerns the latter whereas non-binding technical policies and guidelines address the former.

1. Preventative Rules

The foundational treaty of space law—the Outer Space Treaty[201]—contains a passage that is relevant to efforts to prevent the creation of orbital debris. Article IX declares:

> In the exploration and use of outer space, including the moon and other celestial bodies, States Parties to the Treaty shall be guided by the principle of co-operation and mutual assistance and shall conduct all their activities in outer space . . . with *due regard to the corresponding interests of all other States* Parties to the Treaty. States Parties to the Treaty shall pursue studies of outer space, including the moon and other celestial bodies, and conduct exploration of them so as to *avoid their harmful contamination*. . . .[202]

Article IX then declares that States should consult with other States before engaging in activities which might cause "harmful interference" with the activities of other States and

[200] However, the *Agreement Governing the Activities of States on the Moon and Other Celestial Bodies*, 18 December 1979, 1363 UNTS 3, 18 ILM 1434 [Moon Agreement] will not be considered. The Moon Agreement has not been widely adopted, the major space-faring States are not parties, and its provisions have not become customary international law. For an analysis of how the Moon Agreement applies to the context of orbital debris, see Tan, *supra* note 63 at 159-60.

[201] *Treaty Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies*, 27 January 1967, 610 UNTS 205, 18 UST 2410 [Outer Space Treaty].

[202] *Ibid*. at art. IX (emphasis added).

that any State Party has the right to request consultations if it believes another States' activities has or will cause harmful interference.[203]

The quoted language creates a treaty obligation upon States to take reasonable measures to ensure that its activities do not interfere with the interests of other States or cause harmful contamination. Thus, a State which creates debris in the space environment could be said to be acting without due regard for the interests of other States, causing harmful contamination, and is under a duty to consult.

There are two problems with the provision, however. First, it is impossible to operate in space without creating some amount of debris. So it becomes a matter of degree: how much debris is too much? Obviously, this must be a case-by-case evaluation. Given that outer space "shall be free for exploration and use by all States,"[204] every State can assert that its national interests justified creating the debris in question and that it was acting in accordance with international law. This leads to the second problem, which is how to enforce and apply such an ill-defined obligation. Without specific guidelines, one State would have difficulty proving that another State, by allowing debris to be created, had violated the due regard or harmful contamination clauses in Article IX.[205] Article IX at best encourages States to limit the generation of new orbital debris in a non-specified manner, but there is little chance a State would ever

[203] *Ibid.*
[204] *Ibid.* at art. I.
[205] See Nandasiri Jasentuliyana, "Celebrating Fifty Years of the Chicago Convention Twenty-Five Years After the Moon Landing: Lessons for Space Law," (1994) 19:2 Ann. Air & Sp. L. 429 at 442 [Jasentuliyana, "Lessons for Space Law"]; Lawrence D. Roberts, "Addressing the Problem of Orbital Space Debris: Combining International Regulatory and Liability Regimes" (1992) 15 B.C. Int'l & Comp. L. Rev. 51 at 60-61 [Roberts, "Liability Regimes"].

be held internationally responsible for a violation of Article IX based upon creating ordinary orbital debris.

2. Liability Rules

Articles VI, VII, and VIII of the Outer Space Treaty establish the basic legal framework for dealing with all objects in outer space. Article VI is significant because it makes a State internationally responsible for the activities of its non-governmental entities (such as individuals and corporations) occurring in outer space.[206] When the Outer Space Treaty came into force, private commercial activity in space was virtually non-existent.[207] Today, non-governmental entities make up a substantial proportion of space activity[208] and are therefore the cause of a proportionate amount of orbital debris. Thus, through Article VI, States are directly responsible to other States for the consequences of orbital debris generated by non-governmental entities.

Articles VII addresses State liability.[209] It declares:

> Each State Party to the Treaty that launches or procures the launching of an object into outer space . . . and each State Party from whose territory or facility an object is launched, is internationally liable for damage to another State Party to the Treaty or to its natural or juridical persons by such object or its component parts on the Earth, in air or in outer space.[210]

Article VII includes several concepts important to the issue of orbital debris. First, there are four categories of "launching States:"[211] (1) a State that launches a "space object,"[212]

[206] Outer Space Treaty, *supra* note 201 at art. VI.

[207] Cheng, *supra* note 10 at 607.

[208] For example, between 2001 and 2005, commercial launches into space accounted for 30 percent of the total number of launches. FAA, *2005 Year in Review*, *supra* note 146 at 13.

[209] The concept of responsibility under Article VI is broad enough to encompass liability, but Article VII is an elaboration and clarification of liability. See Cheng, *supra* note 10 at 605-6.

[210] *Ibid*. at art. VII.

[211] The term "launching State" is not used in the Outer Space Treaty, but it does appear in Article I of the *Convention on the International Liability for Damage Caused by Space Objects*, 29 March 1972,

(2) a State that procures the launching of a space object, (3) a State from whose territory a space object is launched, and (4) a State from whose facility a space object is launched. Under this comprehensive definition, multiple States may be jointly liable since multiple States may be involved within each of the four categories. For example, both the US and Canada could jointly procure the launch of a satellite. Second, Article VII makes launching States liable for damage caused by their space objects. Third, it declares that the liability extends to damage caused not only in outer space, but also on Earth or in the atmosphere.

The Liability Convention clarifies and amplifies the liability regime established by Article VII of the Outer Space Treaty. The following provisions are particularly relevant to the discussion concerning orbital debris. Article I of the Liability Convention defines damage as the "loss of life, personal injury or other impairment of health; or loss of or damage to property of States or of persons, natural or juridical, or property of international intergovernmental organizations."[213] The next two articles establish a bifurcated regime of liability, depending on where the damage occurred and what type of object was damaged. Under Article II, a launching State is "absolutely liable" for damage on the surface of the earth or to aircraft in flight.[214] Article III, however, establishes a fault-based system for damage caused by a space object of one launching

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961 UNTS 187, 24 UST 2389 [Liability Convention] as well as Article I of the *Convention on the Registration of Objects Launched into Outer Space*, 12 November 1974, 1023 UNTS 15, 28 UST 695 [Registration Convention].

[212] Similarly, the term "space object" is not used in the Outer Space Treaty, but it appears in the Liability Convention, Registration Convention, the *Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space*, 22 April 1968, 672 UNTS 119, 19 UST 7570 [Rescue Agreement], as well as the Moon Agreement, *supra* note 200.

[213] Liability Convention, *supra* note 211 at art. I(a).

[214] Liability Convention, *supra* note 211 at art. II.

State to a space object (including persons and property on board) of another launching State if the damage occurred in space.[215]

Article VIII of the Outer Space Treaty is the last section that is important to an analysis of orbital debris. It declares that a "State Party to the Treaty on whose registry an object launched into outer space is carried shall retain jurisdiction and control over such object . . . while in outer space."[216] The Registration Convention clarifies this passage in its Article II, stating that "[w]hen a space object is launched into earth orbit or beyond the launching state shall register the space object by means of an entry in an appropriate registry."[217] Read together, these two texts show that only one State, and always one of the launching States, will have jurisdiction and control over space objects it launched.

These sections of the space law treaties discuss State responsibility for "space objects" and "objects launched into outer space." Neither phrase is defined, although they are used interchangeably in some of the treaties. For example, the Rescue Agreement and the Registration Convention use both phrases. However, the Outer Space Treaty only uses the phrase "objects launched into outer space" whereas the Liability Convention only uses the phrase "space object."[218] Although the treaties use inconsistent terminology, this should not be ascribed any significance since there is no agreed upon

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[215] Liability Convention, *supra* note 211 at art. III.

[216] Outer Space Treaty, *supra* note 201 at art. VIII.

[217] Registration Convention, *supra* note 211 at art. II(1). When there are multiple launching States, they jointly determine which one of them should register the object. *Ibid.* at art. II(2).

[218] Read literally, the term space object could be so broadly interpreted as to include meteorites. This would, however, stretch the meaning too far as the clear intent of all the space law treaties is to govern objects made by humans. Nevertheless, this extreme example does show the type of problem that can arise when key terms lack definition.

definition.[219] The closest one can get to a description of the term "space object" appears in the Liability Convention. There, Article I notes "[t]he term 'space object' includes component parts of a space object as well as its launch vehicle and parts thereof."[220]

When discussing the law applicable to orbital debris, some authors divide the discussion into two parts: non-functional payloads (such as intact satellites that have run out of fuel), and other types of debris (such as fragments, microparticulate matter, and litter).[221] Such a distinction is artificial and unnecessary. As Baker notes, every object launched into space has the potential to become debris.[222] The Outer Space Treaty and Liability Convention make a State liable for damage caused by any "object or its component parts" that it launched into outer space.[223] Object does not mean solely the "satellite" or the "payload." The ordinary meaning of the word object extends to every tangible thing on the rocket, including the payload, but also paint, bolts, and every other part of every component part, all the way down to the microscopic level.[224] As most scholars ultimately conclude, both non-functional payloads and every piece of debris in space fall under the category of "space object" within the meaning of the space law

[219] Cheng, *supra* note 10 at 495. Despite the lack of a definition, the *Vienna Convention on the Law of Treaties*, May 22, 1969, 1155 UNTS 331 [Vienna Convention] provides the legal framework for treaty interpretation. Article 31 of the *Vienna Convention* declares that a treaty should be interpreted according to the ordinary meaning of the terms of the treaty and special meaning should be given to words only if the parties so intended. The ordinary meaning of both phrases would appear to encompass all manmade objects in outer space, including debris. Although the Vienna Convention does not apply retroactively and therefore does not apply to any of the space law treaties, its articles either declare existing principles of customary international law or they are "presumptive evidence of emergent rules of general international law." Ian Brownlie, *Principles of Public International Law* (New York: Oxford University Press, 2003) at 580.

[220] Liability Convention, *supra* note 211 at art. I.

[221] See, *e.g.*, Cheng, *supra* note 10 at 506; Baker, *Space Debris*, *supra* note 41 at 61-5.

[222] Baker, *Space Debris*, *supra* note 41 at 64.

[223] Outer Space Treaty, *supra* note 201 at art. VII; Liability Convention, *supra* note 211 at arts. I-III.

[224] The problem of determining State responsibility for small debris is another matter. See Part II.D.1.a) above.

treaties.[225] One scholar even observes that "a lump of rock launched into outer space for no reason at all but for the fun of it must still be considered a space object."[226] Thus, the consequence of (liability)—but not the creation of—orbital debris is currently governed by the provisions previously mentioned in this Part.[227] Whether those rules are adequate or not will be discussed in Parts V and VI below.

B. Customary International Law

Having reviewed the limited regime of "hard law" (treaties) that apply to orbital debris, the next issue is whether there are any customary norms concerning orbital debris. Customary international law is recognized as a binding form of law and in the hierarchy of international law, falls immediately below treaties.[228] For a norm-creating provision to become customary international law—a result which is "not lightly to be regarded as having been attained"[229]—the rule must be "a settled practice . . . carried out in such a way, as to be evidence of a belief that this practice is rendered obligatory by the existence

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[225] Cheng, *supra* note 10 at 506; Luboš Perek, "Management Issues Concerning Space Debris" in Dansey, *supra* note 13, 587 at 589 [Perek, "Management Issues"]. A more comprehensive definition of "space object" that would undoubtedly have encompassed orbital debris was considered during the discussion leading up to the Liability Convention, but was not adopted. Cheng, *supra* note 10 at 325. The proposed definition would have included launch vehicles "as well as all component parts on board, detached from or torn from the space object." *Ibid*.

[226] *Ibid*. at 506.

[227] *Ibid.*; Stephen Gorove, *Developments in Space Law: Issues and Policies* (Boston: Martinus Nijhoff, 1991) at 166-67; UN COPUOS Legal Subcommittee, 41st Sess., 665th Mtg., UN Doc. COPUOS/LEGAL/T.665, 2002, online: <http://www.unoosa.org/pdf/reports/transcripts/legal/LEGALT_665E.pdf> (comments of Dr. Gabriel Lafferranderie, European Space Agency representative); I.H.Ph. Diederiks-Verschoor, "Harm Producing Events Caused by Fragments of Space Objects (Debris)" (1983) *Proceedings of the 25th Colloquium on the Law of Outer Space* 1 at 3. Of course, some commentators disagree or are at least uncertain whether orbital debris is governed by the existing liability rules. See *e.g.* Christopher D. Williams, "Space: The Cluttered Frontier" (1995) 60 J. Air L. & Com. 1139 at 1147.

[228] *Statute of the International Court of Justice*, 3 Bevans 1179, 59 Stat. 1031, at art. 38(1), online: <http://www.icj-cij.org/icjwww/ibasicdocuments/ibasictext/ibasicstatute.htm>.

[229] *North Sea Continental Shelf Cases (Federal Republic of Germany v. Denmark and Federal Republic of Germany v. Netherlands*, [1969] I.C.J. Rep. 3 at para. 71.

of a rule of law requiring it."[230] In other words, the substance of customary international law is "primarily in the actual practice and *opinio juris* of States."[231] In addition, the State practice must be "extensive and virtually uniform," particularly with respect to States whose interests are "specially affected."[232]

State practice is the first element. As will be discussed below, based on national and international efforts aimed at mitigating new debris,[233] it seems possible to draw a broad conclusion that there is consistent State practice, among the specially affected States, to limit the creation of new orbital debris when it is cost-effective and can be accomplished without negative mission impact.[234] One may go further and assert that even more specific rules have emerged, such as a requirement to boost satellites out of GEO or to deorbit satellites in LEO. On the other hand, others may argue that for decades, the practice of States has been merely to abandon satellites in space and take no efforts to minimize the creation of new debris. They would suggest that the recent innovation in orbital debris mitigation policies have not existed long enough to qualify as a consistent State practice.[235]

Whether or not the first element is satisfied, the second element, *opinio juris*, has clearly not been established, however. In order for the State practice to be customary

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[230] *Ibid*. at para. 77.

[231] *Legality of the Threat or Use of Nuclear Weapons, supra* note 181 at para. 64.

[232] *North Sea Continental Shelf Cases, supra* note 229 at para. 74.

[233] See Parts IV.C-IV.E, below.

[234] Of course, this addresses only the preventative rules and not the consequence (liability) rules. There has been no application of the Liability Convention for damage occurring in space. The only application of the Liability Convention arose as a result of the Russian Cosmos 954 satellite's crash into Canadian territory in 1978. Russia eventually settled with Canada. See generally Alexander F. Cohen, "Cosmos 954 and the International Law of Satellite Accidents" (1985) 10 Yale J. Int'l. L. 78. Thus, there is no established State practice based on the Liability Convention's consequence-based rules.

[235] The length of the period of time over which State practice develops is not especially important; what matters is the extent of the practice and *opinio juris*. *North Sea Continental Shelf Cases, supra* note 229 at para. 74; Cheng, *supra* note 10 at 136-42.

international law, States must feel obligated to follow the practice. If there was any question concerning this before, it was definitely resolved by draft guidelines promulgated in February 2006 by the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) Scientific and Technical Subcommittee. The guidelines clearly state their orbital debris mitigating principles are not binding international law.[236] Therefore, it is safe to conclude that, as of now, no specific customary international law governs orbital debris.

Even though there is no customary international law that is unique to orbital debris, rules of general international law still apply in space. Article III of the Outer Space Treaty makes the whole of international law applicable to outer space.[237] Relevant principles of general international law are discussed in the following paragraphs.

Under international law, every State has an obligation "not to allow knowingly its territory to be used for acts contrary to the rights of other States."[238] This obligation extends to persons and private entities under the State's effective jurisdiction.[239] States are not only responsible for their own acts and the acts of their agents; [240] they also have a duty to use due diligence in "preventing, suppressing, and repressing injurious acts" by

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[236] See *infra* note 327 and accompanying text.

[237] Article III of the Outer Space Treaty declares: "States Parties to the Treaty shall carry on activities in the exploration and use of outer space . . . in accordance with international law, including the Charter of the United Nations. . . ." Outer Space Treaty, *supra* note 201 at art. III. Therefore, all general international law is made applicable to space except where there is a conflict, in which case the more specific rules of space law will control. See Ian Sinclair, *The Vienna Convention on the Law of Treaties* (Dover, N.H.: Manchester University Press, 1984) at 96.

[238] *Corfu Channel Case (United Kingdom v. Albania)*, Merits, [1949] I.C.J. Rep. 4, 22; *Trail Smelter Arbitration (United States of America v. Canada)* (1941), 3 R.I.A.A. 1911, reprinted in, 35 Am. J. Int'l L. 684 at 713 ("A State owes at all times a duty to protect other States against injurious acts by individuals from within its jurisdiction.").

[239] Cheng, *supra* note 10 at 616.

[240] Brownlie, *supra* note 219 at 431-439; Cheng, *supra* note 10 at 605.

their nationals.[241] If a State fails to use due diligence to protect a foreign State, the State will be directly responsible for this failure "since failures by its officials will be imputed to the State as its own acts."[242] Moreover, the duty to protect foreign States can be heightened by treaty.

The Outer Space Treaty imposes a heightened duty to protect other States. Article VI of the Outer Space Treaty declares that direct State responsibility for national activities extends to activities "carried on . . . by non-governmental entities" for the express purpose of "assuring that national activities are carried out in conformity with the provisions" of the Outer Space Treaty.[243] In this regard, Article VI mandates that the "activities of non-governmental entities in outer space . . . shall require authorization and continuing supervision by the appropriate State." The acts of authorization and continuing supervision presuppose a heightened duty. The effect of Articles III and VI of the Outer Space Treaty is to apply the *Corfu Channel* and *Trail Smelter* principles to governmental and non-governmental activity in outer space and to heighten a State's duty of due diligence.

Nevertheless, these duties should not be seen as a significant factor in limiting the creation of new orbital debris. In the context of orbital debris, the rule has no more teeth than does Article IX of the Outer Space Treaty.[244] Additionally, it is important to remember that outer space is "an environment subjected to a *special* legal regime."[245]

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[241] Cheng, *supra* note 10 at 604.
[242] *Ibid.* at 604, 616.
[243] Outer Space Treaty, *supra* note 201 at art. VI.
[244] See *supra* notes 201-204 and accompanying text.
[245] Ram S. Jakhu, "The Legal Status of the Geostationary Orbit" (1982) 7 Ann. Air & Sp. L. 333 at 347 (emphasis added) (quoting Manfred Lachs, *The Law of Outer Space: An Experience in Contemporary Law Making* (Leiden: Sijthoff, 1972)).

Therefore, it is only with caution that one should introduce concepts and analogies from general international law into the law applicable to the use and exploration of outer space.[246] For example, both the *Corfu Channel Case*[247] and the *Trail Smelter*[248] arbitration involved harm to a State's national territory or property. That is analogous to orbital debris causing damage to a functioning satellite of another State, in which case the specific rules of the Liability Convention will apply. Orbital debris threatens more than just satellites, however; it pollutes the environment of outer space in such a way that certain areas of space may become unusable. Outer space is a global commons, not subject to "national appropriation by claim of sovereignty, by means of use or occupation, or by any other means."[249] Therefore, it is questionable whether the principles of the *Corfu Channel Case* and the *Trail Smelter* arbitration apply to space, an area completely outside the territorial jurisdiction of States.

On the other hand, well-established customary international law on transboundary environmental damage does exist. For example Principle 21 of the 1972 Stockholm Declaration declares "States have . . . the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States *or of*

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[246] *Ibid*.

[247] The case arose out of the explosions of mines by which some British warships suffered damage while passing through the Corfu Channel in 1946 in a part of Albanian territorial waters which had been previously swept. The ships were severely damaged and members of the crew were killed. The International Court of Justice found that Albania was responsible under international law for the explosions, damage, and loss of life in Albanian waters. *Corfu Channel Case*, *supra* note 238.

[248] From approximately 1925 to 1937, an ore smelting plant in British Columbia, Canada created tons of sulfur dioxide fumes. The fumes caused significant environmental damage to the State of Washington, for which the US Government sought and was awarded compensation from Canada. *Trail Smelter Arbitration*, *supra* note 238.

[249] Outer Space Treaty, *supra* note 201 at art. II.

areas beyond the limits of national jurisdiction."[250] Although the Declaration as such is not legally binding, this principle is recognized as customary international law, which is a legally binding obligation.[251] However, this is substantially the same as the harmful contamination rule in Article IX of the Outer Space Treaty, bringing the analysis back to where it began.

Finally, a concept known as the precautionary principle could play a role in the development of international environmental law for outer space. There is no universally agreed upon elaboration of the principle,[252] however Principle 15 of the Rio Declaration contains a generally accepted description:

> In order to protect the environment, the precautionary approach shall be widely applied by States according to their abilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.[253]

Many commentators assert the precautionary principle reflects customary international law.[254] In the absence of scientific certainty, the principle essentially requires States either to avoid engaging in the harm-producing activity or to weigh the benefits against the potential environmental damage and take appropriate steps to mitigate the anticipated

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[250] UN, *Report of the United Nations Conference on the Human Environment* (New York: UN, 1973) at 5 (also available as UN Doc. A/Conf.48/14/Rev. 1).

[251] Alexandre Kiss & Dinah Shelton, *International Environmental Law*, 3d ed. (Ardsley, NY: Transnational Publishers, 2004) at 85; Restatement of the Law (Third), The Foreign Relations Law of the United States (St. Paul, MN: American Law Institute Publishers, 1987) at § 601(1).

[252] Robert V. Percival, "The North American Symposium on the Judiciary and Environmental Law: Who's Afraid of the Precautionary Principle?" (2006) 23 Pace Envtl. L. Rev. 21 at 28. See also Steven A. Mirmina & David J. Den Herder, "Nuclear Power Sources and Future Space Exploration" (2005) 6 Chi. J. Int'l L. 149 at 164 ["Nuclear Power Sources"].

[253] UN, *Report of the United Nations Conference on Environment & Development Held in Rio de Janeiro 3-14 June 1992*, (New York: UN, 1992), Principle 15 at 6 (also available as UN Doc. A/CONF.151/26/Rev.l (Vol. I)).

[254] Percival, *supra* note 252, at 21.

environmental harm.[255] Whether the precautionary principle applies to outer space or not, the international community and individual States have responded to concerns about orbital debris and have implemented a series of mitigating steps. These mitigation measures are discussed in the Parts IV.C-IV.F below.

C. US Debris Mitigation

The US has long been concerned about the impacts of orbital debris on the space environment and has developed a series of technical and policy based solutions. As early as 1981, NASA initiated a 10-year assessment plan for orbital debris.[256] In 1987, the DoD addressed debris issues for the first time in its official Space Policy: "DoD will seek to minimize the impact of space debris on its military operations. Design and operations of DoD space tests, experiments and systems will strive to minimize or reduce accumulation of space debris consistent with mission requirements."[257] President Ronald Reagan's 1988 Presidential Directive on National Space Policy also called for all space sectors to minimize debris consistent with mission requirements and cost effectiveness.[258]

The US government issued a report in 1989 on orbital debris, followed the next year by a Congressional background paper.[259] Following these reports, NASA began measuring orbital debris with radar and modeling it with computer simulations. NASA

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[255] Mirmina, *supra* note 252 at 164.

[256] F. Kenneth Schwetje, "Current U.S. Initiatives to Control Space Debris" (1988) *Proceedings of the 30th Colloquium on the Law of Outer Space* 163 at 168. The purpose of the plan was to begin the process for US policies and eventually international agreements on orbital debris. Johnson, *Space Debris*, *supra* note 79 at 85.

[257] *Ibid.* at 166. The DoD was the first US Government agency to create a written orbital debris policy. *National Research on Space Debris, Safety of Space Objects with Nuclear Power Sources on Board and Problems Relating to Their Collision with Space Debris*, UN COPUOS, 2003, UN Doc. A/AC.105/789/Add.1, 2003 at 8.

[258] *Presidential Directive on National Space Policy* Fact Sheet (11 February 1988), online: <http://www.au.af.mil/au/awc/awcgate/policy88.htm>.

[259] US Congress, Office of Technology Assessment, *Orbital Debris: A Space Environmental Problem—Background Paper*, OTA-BP-ISC-72 (Washington: US Government Printing Office, 1990).

also entered into bilateral discussions with the space agencies of other major space-faring States. These discussions eventually led to multilateral discussions and the creation of the Interagency Space Debris Coordination Committee (IADC).[260] Since then, the overall US policy and the policies of the individual US agencies involved with space have been refined and amended many times.

In September 1996, President Bill Clinton issued the latest version of the National Space Policy.[261] The policy fact sheet[262] states:

> The United States will seek to minimize the creation of space debris. NASA, the intelligence community, and DoD, in cooperation with the private sector, will develop design guidelines for future Government procurements of spacecraft, launch vehicles, and services. The design and operation of space tests, experiments, and systems will minimize or reduce accumulation of space debris consistent with mission requirements and cost-effectiveness.

These two sentences show the overall objective for US Government agencies. Each agency is responsible for creating its own specific policies on orbital debris in order to achieve the goal of minimizing the creation of debris. The policies of the US Government agencies involved in using, or in licensing others to use, space are briefly outlined below.

1. NASA

The current NASA policy states that it will "limit the generation of orbital debris . . . consistent with mission requirements and cost effectiveness."[263] To

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[260] Williams, *supra* note 227 at 1167; George M. Levin, "U.S. Initiatives in the International Effort to Mitigate the Orbital Debris Environment" (1996) 1:2 *Orbital Debris Quarterly News* 4, online: <http://www.orbitaldebris.jsc.nasa.gov/newsletter/pdfs/ODQNV1i2.pdf>. For a discussion of the IADC, see Part IV.D below.

[261] *National Space Policy*, The White House, National Science and Technology Council Fact Sheet (19 September 1996), online: <http://www.au.af.mil/au/awc/awcgate/sep96.htm>. The policy is currently under revision by President George W. Bush's administration.

[262] The actual policy is not publicly available.

accomplish this objective, the NASA policy requires a review of each spacecraft to assess its debris creating potential.[264] This policy is further implemented by a NASA Safety Standard.[265] The Safety Standard requires assessments for (1) debris generated during normal operations, (2) debris created by accidental explosions and intentional breakups, (3) debris resulting from on-orbit collisions, and (4) safe disposal options for spacecraft at the end of their useful life.[266] The NASA guidelines for each of these areas are summarized next.[267]

a) Normal Operations

Debris in LEO that has a diameter .01 centimeters or larger is subject to certain criteria that are related to the amount, size, and anticipated orbital life of the debris. Debris in GEO that is five centimeters or larger should be lowered (through natural decay) to 300 kilometers below GEO within 25 years.[268] For each of the four required assessment categories, the Safety Standard suggests specific mitigation measures that could help ensure a particular mission falls within the guidelines. These are not part of the guidelines, but are simply suggestions for how to make the mission compliant with the standards. For the normal operations category, the document suggests releasing

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[263] NASA Policy Directive 8710.3B, *NASA Policy for Limiting Orbital Debris Generation* (27 January 2003) at para. 1.

[264] *Ibid.*

[265] NASA Safety Standard 1740.14, *Guidelines and Assessment Procedures for Limiting Orbital Debris* (August 1995).

[266] *Ibid.* at 1-1. The standard also requires assessments for the possibility of parts of the satellite striking Earth after an atmospheric re-entry; however, this thesis focuses on policies concerning debris that remain in space.

[267] The content of the NASA Safety Standard is highly technical. Other US Government agencies, other States, and other international bodies also have detailed technical standards, but they will not be reviewed in as much detail. NASA's standards are used as an example because they are the most thorough and comprehensive available and therefore they provide a benchmark for comparison.

[268] *Ibid*. at 3-2. This category of debris includes operational debris but excludes spacecraft, as they will normally be transferred to areas above GEO. *Ibid*. at 6-1.

debris near times of peak solar activity (which will cause the object's orbit to decay more quickly), releasing debris when the perturbations from the sun's and moon's gravity will reduce the orbital lifetime, or capturing the debris (such as explosive bolts used to separate spacecraft stages) within another part of the spacecraft to prevent the debris from being released.[269]

b) Accidental Explosions and Intentional Breakups

For accidents, the goals are to limit the probability of accidental explosions to less than one chance in 10,000 and to deplete the on-board stored energy at the end of mission life.[270] NASA objectives for intentional breakups include limiting the long-term risk to other space objects by performing the planned test or collision at an altitude such that debris larger than 0.1 centimeters will de-orbit within one year. The short-term risk to other objects is mitigated by requiring that debris larger than 0.1 centimeters have a very small probability (one in a million) of impacting nearby objects.[271] Specific mitigation measures include lowering the altitude at which the breakup occurs, lowering the perigee altitude, and moving the time a few minutes earlier or later to allow the spacecraft to move away from other known objects.[272]

c) On-Orbit Collisions

The NASA criteria are met if the probability of collisions with small objects (from about 0.1 centimeters to one centimeter) is one in 100 or less. In order to assess this probability, the relevant factor is whether the spacecraft will be unable to complete its scheduled end-of-mission disposal plan. In other words, engineers evaluate whether

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[269] *Ibid*. at 3-7.
[270] *Ibid*. at 4-2.
[271] *Ibid.* at 4-4.
[272] *Ibid.* at 4-5 to 4-6.

the systems necessary to move the craft to a safe orbit or to cause it to re-enter the atmosphere are likely to last for the duration of the mission. For collisions with larger objects, the probability should be one in 1,000 or less.[273] Mitigation measures for LEO include changing the altitude or the spacecraft design to lessen the cross-sectional area. For any orbit, design changes can include adding shielding to protect critical components, moving critical components towards the center of the craft allowing less critical areas to act as a shield, using redundant systems, and compartmentalizing areas on the spacecraft.[274]

d) Spacecraft Disposal

The NASA guidelines establish criteria that are dependent upon the planned altitude of the spacecraft at the end of its mission. For all orbits, the criteria are met if the disposal plan has a 99 percent probability of success. For LEO, the spacecraft should either (1) reenter the earth's atmosphere within 25 years, (2) be transferred to an orbit between LEO and GEO, or (3) be directly retrieved and removed within 10 years.[275] For all other orbits,[276] the spacecraft should either be moved to 300 kilometers above GEO or to 500 kilometers below GEO. The mission planners should choose the strategy that is least likely to leave the spacecraft stranded in GEO if the disposal operation fails.[277] To increase the likelihood of success, the Safety Standard suggests adding redundant components to the post-mission disposal system.[278]

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[273] *Ibid.* at 5-1.
[274] *Ibid.* at 5-6.
[275] *Ibid*. at 6-3.
[276] There is an exception for near-circular 12-hour orbits between 19,900 kilometers and 20,500 kilometers in altitude. *Ibid*.
[277] *Ibid*.
[278] *Ibid.* at 6-7.

2. Department of Defense

The DoD has directed that debris should be minimized, consistent with mission requirements and cost effectiveness.[279] Furthermore, at the end of a spacecraft's mission, it should be removed from space or placed in a storage orbit.[280] Specific details are provided in a DoD Instruction,[281] which declares that debris mitigation must be taken into account when purchasing and operating spacecraft.[282] The instruction mandates that spacecraft designs minimize debris during normal operations for all earth orbits. Planned operational debris larger than .5 centimeters that is anticipated to remain on orbit for more than 25 years requires special evaluation and justification.[283]

Regarding debris creating potential other than in normal operations, the DoD Instruction states that the risk of accidental explosions shall be controlled through design and operation and that all unneeded energy sources shall be depleted as soon as possible. Furthermore, spacecraft should be designed in such a way that there is a small probability that debris smaller than one centimeter that collides with the spacecraft will prevent post-mission disposal.[284] Finally, at the end of their useful life all spacecraft in Earth orbit must be disposed of either by (1) atmospheric reentry within 25 years, (2) direct retrieval as soon as possible, or (3) transfer to a disposal orbit. A disposal orbit should be in an

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[279] Department of Defense Directive 3100.10, *Space Policy* (9 July 1999) at paras. 4.11.5, 4.11.6.
[280] *Ibid.*
[281] Department of Defense Instruction 3100.12, *Space Support* (14 September 2000).
[282] *Ibid.* at para. 6.3.
[283] *Ibid*. at para. 6.3.1.
[284] *Ibid.* at para. 6.3.2.

orbit between LEO and 500 kilometers below GEO, in an orbit 300 kilometers or more above GEO, or in an orbit around the sun rather than around the earth.[285]

3. Other US Government Agencies

Other US agencies have their own rules concerning debris mitigation. For example, the National Oceanic and Atmospheric Administration (NOAA) is responsible for licensing commercial remote sensing satellite systems. The statute authorizing this activity, the Land Remote Sensing Policy Act of 1992, declares that as a condition of the license, the operator must dispose of the satellites in a manner approved by the US Government.[286] The statute is implemented by NOAA regulations.[287] The regulations, however, are silent concerning the specifics of disposal required. The only guidelines note that NOAA will make a case-by-case determination whether the applicant's proposed atmospheric re-entry, transfer to storage orbit, or direct retrieval plan is satisfactory.[288]

Similarly, the Federal Communications Commission (FCC) is responsible for licensing commercial communications satellites.[289] The FCC evaluates operational aspects and end-of-life disposal plans to ensure that systems requiring an FCC license are designed and operated in ways that will minimize the creation of new debris.[290] There is

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[285] *Ibid.* at para. 6.4. Although not discussed in the DoD Instruction, disposal orbits should also avoid highly congested areas of MEO, such as those used by the existing and proposed navigation satellite systems.

[286] 15 U.S.C. § 5622(b)(4).

[287] 15 C.F.R. §§ 960.1-960.15.

[288] *Licensing of Private Land Remote Sensing Space Systems, (Interim Final Rule)*, 65 Fed. Reg. 46822 (31 July 2000).

[289] 47 U.S.C. § 154.

[290] 47 C.F.R. § 25.114(d)(14). Although this subsection applies to the majority of FCC licenses falling under the "common carrier" category, there are similar rules for licenses in the Experimental Radio Service, 47 C.F.R. § 5.63(e), and the Amateur Radio Service, 47 C.F.R. § 97.207(g)(1). These rules were adopted in 2004, in response to guidelines issued by the IADC in 2002. Prior to 2004, the FCC

a further FCC requirement that spacecraft in GEO must be raised by a certain minimum altitude at the end of their mission.[291] For remote sensing satellites, in addition to the NOAA license requirement, the FCC licenses the radio-frequency aspects.[292] The FCC has determined that because of the lack of specificity in the NOAA regulations, the FCC will also examine debris mitigation issues for remote sensing satellites.[293]

Finally, the Department of Transportation (DOT) licenses space launch vehicles.[294] Launch vehicles are different than satellites in that their function ends once the satellite reaches orbit. Therefore, the DOT merely requires that all on-board fuel sources be depleted in order to prevent accidental debris-generating explosions.[295] No specific deorbiting procedures are required.

D. Inter-Agency Debris Coordination Committee (IADC)

The IADC has been a significant international effort aimed at preventing and mitigating orbital debris. It is an international forum of governmental bodies for the coordination of activities related to the issues of orbital debris and is composed of experts from the major space-faring States' space agencies.[296] The IADC was officially formed

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had only very limited requirements concerning orbital debris mitigation. *Mitigation of Orbital Debris*, 69 Fed. Reg. 54581 (September 9, 2004).

[291] The minimum required altitude is a function of the solar radiation and the area-to-mass ratio of the spacecraft. 47 C.F.R. § 25.283(a).

[292] K. Kensinger, S. Duall, & S. Persaud, "The United States Federal Communication Commission's Regulations Concerning Mitigation of Orbital Debris" in Dansey, *supra* note 13, 571 at 575.

[293] *Ibid*.

[294] 49 U.S.C. § 70105. This is accomplished through the Office of the Associate Administrator for Commercial Space Transportation, a part of the Federal Aviation Administration.

[295] 14 C.F.R. §§ 415.39 & 431.43. In some cases, the prospective licensee must also assess the risk of debris causing injury upon reentry into Earth's atmosphere. 14 C.F.R. § 440 Appendix A.

[296] Membership includes the Italian Space Agency (ASI), the British National Space Centre (BNSC), the French Centre National d'Etudes Spatiales (CNES), the China National Space Administration (CNSA), the German Deutsches Zentrum für Luft-und Raumfahrt e.V. (DLR), the European Space Agency (ESA), the Indian Space Research Organisation (ISRO), the Japan Aerospace Exploration Agency (JAXA), NASA, the National Space Agency of the Ukraine (NSAU), and the Russian Federal Space

in October 1993, although bilateral discussion on orbital debris issues had occurred prior to that date.[297] The IADC charter is a formal structure, signed by representatives of all the member agencies, and entitled "Terms of Reference for the Inter-Agency Space Debris Coordination Committee."[298] The stated purpose of the IADC is to exchange information on orbital debris research, facilitate cooperation in orbital debris research, review the progress of cooperative activities, and to identify debris mitigation options.[299]

The IADC does not create rules binding on member agencies. Nevertheless, pursuant to its charter, the IADC developed and published in 2002 the "IADC Space Debris Mitigation Guidelines."[300] The IADC Guidelines are based on the fundamental principles present in the national policies of the member agencies and were agreed to by consensus.[301] The IADC Guidelines encourage all users of Earth orbit to consider four basic areas when designing new spacecraft and operating existing ones, each of which is briefly elaborated below.[302]

(1) Limitation of debris released during normal operations. The IADC Guidelines state that systems should be designed to avoid any release of debris where

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Agency (ROSCOSMOS). *Terms of Reference for the Inter-Agency Space Debris Coordination Committee* (2004) [Terms of Reference], online: <http://www.iadc-online.org/index.cgi?item=torp_pdf>.

[297] IADC Presentation to 34th UN COPUOS STSC, February 1997, IADC-97-01, online: <http://www.iadc-online.org/docs_pub/34th_UN_COPUOS_STSC.pdf>.

[298] Terms of Reference, *supra* note 296 at 1.

[299] *Ibid*. at 4.

[300] *IADC Space Debris Mitigation Guidelines* (2002) [IADC Guidelines], online: <http://www.iadc-online.org/docs_pub/IADC-101502.Mit.Guidelines.pdf>. The IADC Guidelines have been elaborated upon by *Support to the IADC Space Debris Mitigation Guidelines* (2004), online: <http://www.iadc-online.org/docs_pub/IADC.SD.AI20.3.10.2004.pdf>. Additionally, the IADC has published detailed information about spacecraft debris protection design. *Protection Manual* (2004), online: <http://www.iadc-online.org/docs_pub/IADC.PM.v3.3.04.04.2004.pdf>.

[301] *Ibid.* at iv.

[302] *Ibid*. at 1.

possible. When this is not feasible, debris release should be planned in such a way as to limit the amount of debris in number, area, and orbital life.[303]

(2) Minimization of the potential for on-orbit break-ups. The IADC Guidelines note that the potential for break-up can be lessened by taking steps to release or protect stored energy sources like propellant and batteries (a process known as passivation); by continuously monitoring the condition of spacecraft and taking action when necessary to avoid a break-up; and avoiding intentional destruction that increases the risk to other spacecraft.[304]

(3) Post-mission disposal. The IADC Guidelines call for different procedures for different orbits. Spacecraft in LEO should be de-orbited, moved closer to Earth to lower the orbital lifetime, or directly retrieved.[305] Spacecraft in GEO should be raised at least 235 kilometers above the nominal GEO altitude.[306] For all other orbits, spacecraft should follow the guidelines for LEO where possible, or at least be moved away from congested orbital areas.[307]

(4) Prevention of on-orbit collisions. When planning a mission for a spacecraft, the plan should take into account the probability of collision with all known objects during the spacecraft's lifetime.[308] Further, when reliable data is available, spacecraft should be maneuvered to avoid collision risk and spacecraft should be designed in such a

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[303] *Ibid.* at 4.
[304] *Ibid.* at 4-5.
[305] *Ibid*. at 5-6.
[306] As with the FCC rules, see *supra* note 291, the exact altitude is a function of the solar radiation and the area to mass ratio of the spacecraft. *Ibid.* at 5.
[307] *Ibid.* at 6.
[308] *Ibid.*

way that if the spacecraft does collide with small debris, the probability of a loss of control is low.[309]

The IADC Guidelines, and even the IADC itself, are not a *revolution* in how the problem of orbital debris is being addressed. The individual space-faring States already have national rules or policies in place to implement orbital debris mitigation, in varying degrees. For example, on the macro level, there is little difference between the rules in the US, which came first, and the IADC Guidelines. In fact, the US endorses the IADC Guidelines and declares it is implementing domestic policies consistent with them.[310] Nevertheless, the IADC Guidelines and the IADC itself are an important *evolution* in the orbital debris problem in two ways. First, they have internationalized the discussion. Second, they have served as a precursor to, and perhaps even as the impetus for, discussions in the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS).

E. Committee on the Peaceful Uses of Outer Space (COPUOS)

The former USSR launched the first spacecraft, Sputnik I, on 4 October 1957.[311] COPUOS was created little more than a year later as an ad hoc United Nations (UN) committee with 18 members for the purposes of considering international cooperation in space and legal issues concerning the exploration of space.[312] It became a permanent

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[309] *Ibid.*

[310] International Cooperation on the Peaceful Uses of Outer Space, Remarks by Kenneth Hodgkins, US Adviser to the Fifty-Ninth Session of the UN General Assembly, 2004, online: <http://www.state.gov/g/oes/rls/rm/2004/37827.htm>.

[311] Baker, *Space Debris, supra* note 41 at 87.

[312] *Question of the Peaceful Use of Outer Space*, GA Res. 1348(XIII), UN GAOR, 1958.

committee the following year[313] and is presently one of the largest UN committees with 67 members.[314] The full committee and each of its two subcommittees—the Scientific and Technical Subcommittee and the Legal Subcommittee—meet annually and conduct their work on the basis of consensus.[315] In its early years, COPUOS was very effective and through the Legal Subcommittee drafted all five space law treaties.[316] Since the Moon Agreement in 1979, COPUOS has only forwarded to the General Assembly a few non-binding principles, which is a "significant departure from previous law making efforts" and "reflect[s] a growing resistance of some of the major players in space politics to create too stringent a body of space law."[317] The discussion in COPUOS concerning orbital debris is a classic example of COPUOS' inability to act quickly and decisively since the conclusion of the final space law treaty.[318]

The United Nations has been concerned about orbital debris nearly as long as the United States. A General Assembly Resolution in 1989 noted "it is essential that Member States pay more attention to the problem of collisions with space debris and other aspects of space debris, and calls for the continuation of national research on that question."[319] This statement was issued shortly after the first US Presidential space

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[313] *International Co-operation in the Peaceful Uses of Outer Space*, GA Res. 1472(XIV), UN GAOR, 1959.

[314] United Nations Committee on the Peaceful Uses of Outer Space, online: <http://www.unoosa.org/oosa/en/COPUOS/copuos.html>.

[315] *Ibid*.

[316] Eilene Galloway, "Creating Space Law" in Nandasiri Jasentuliyana, *Space Law: Development and Scope* (Westport, Conn.: Praeger, 1992) 239 at 248-9.

[317] Peter Jankowitsch, "The Role of the United Nations in Outer Space Law Development: Past Achievements and New Challenges" (1998) 26 J. Space L. 101 at 108-9.

[318] *Ibid.* at 109 ("The apparent unwillingness to adopt new space regulations and complete the existing body of space law has become visible once again as first efforts to find legal solutions to the problem of space debris have failed.").

[319] *International Co-operation in the Peaceful Uses of Outer Space*, GA Res. 44/46, UN GAOR, 1989 at para. 23.

policy addressing orbital debris in 1988.[320] In 1993, the General Assembly called upon States to provide information to the Scientific and Technical Subcommittee and commented that the subject could be discussed in COPUOS in the future.[321] COPUOS acted upon this recommendation at its next meeting and the issue of orbital debris appeared on the agenda of the Scientific and Technical Subcommittee in 1994.[322] As a result of its work, the Subcommittee published a 50 page technical report in 1999.[323] All of the subcommittee's work, however, was in the nature of developing background material that was already known to the space-faring States and to the IADC. The subcommittee did not develop guidelines or practices concerning orbital debris mitigation; that would wait until the IADC completed its own Guidelines.

At the February 2003 session of the Scientific and Technical Subcommittee, the IADC presented its Space Debris Mitigation Guidelines.[324] This prompted the subcommittee to create a Space Debris Working Group.[325] The group began the task of revising and updating the IADC Guidelines by working closely with the IADC.[326] The

[320] See *supra* note 258 and accompanying text.

[321] *International Cooperation in the Peaceful Uses of Outer Space*, GA Res. 47/67, UN GAOR, 1993 at paras. 24-26.

[322] *Report of the Committee on the Peaceful Uses of Outer Space*, UN COPUOS, UN Doc. A/AC.105/L.202, 1993 at para. 84; *Report of the Scientific and Technical Subcommittee on the Work of its Thirty-First Session*, UN COPUOS, UN Doc. A/AC.105/571, 1994 at paras. 63-74. The following year, the subcommittee adopted a "flexible" three year work plan. *Report of the Scientific and Technical Subcommittee on the Work of its Thirty-Second Session*, UN COPUOS, UN Doc. A/AC.105/605, 1995.

[323] *Technical Report on Space Debris*, *supra* note 99.

[324] *Report of the Scientific and Technical Subcommittee on the Work of its Fortieth Session*, UN COPUOS, UN Doc. A/AC.105/804, 2003 at para. 121.

[325] *Report of the Scientific and Technical Subcommittee on the Work of its Forty-First Session*, UN COPUOS, UN Doc. A/AC.105/823, 2004 at 20.

[326] *Ibid.* at 20, 41. The IADC and the Working Group met in Vancouver, Canada in October 2004 and the IADC agreed to make minor changes to the IADC Guidelines, but rejected other proposed changes. *Consideration by the Inter-Agency Space Debris Coordination Committee of the Comments Received from Member States of the Committee on the Peaceful Uses of Outer Space on the Proposals on Space Debris Mitigation and Results of the Consultative Meeting of the Inter-Agency Space Debris*

result is a 2006 draft set of "high-level qualitative guidelines" that are based on the work of the IADC but are the product of the working group.[327] There are seven guidelines, which closely track the principles of the IADC Guidelines, but lack the specificity of the IADC product and contain no technical details whatsoever.[328] The working group guidelines declare that they encourage all States to voluntarily apply the guidelines, recognizing that (1) there may be exceptions to their implementation in certain cases and (2) they are not legally binding under international law.[329] The working group report will be circulated for final comments, with the goal of submitting them to the full Scientific and Technical Subcommittee for adoption in 2007.[330]

From the beginning of the UN discussion, the Legal Subcommittee has refrained from getting involved.[331] That has remained unchanged through today.[332] Some delegations have tried to get orbital debris added as an agenda item, but consensus is necessary to create a new agenda item and, as yet, there has been no consensus to do so. For examples of efforts made to get the topic added to the agenda, one need only look at the Legal Subcommittee's annual reports. Since 1995, the topic of orbital debris has been included in the Legal Subcommittee's informal discussions on the possibility of adding

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Coordination Committee and the Committee on the Peaceful Uses of Outer Space Held in Vancouver, Canada, on 4 October 2004, UN COPUOS, UN Doc. A/AC.105/C.1/L.279, 2005. So far, the IADC Guidelines have not been updated.

[327] *Progress Report of the Working Group on Space Debris, Submitted by the Chairman of the Working Group*, UN COPUOS, UN Doc. A/AC.105/C.1/L.284, 2006, at 2.

[328] *Ibid*. at 3-4.

[329] *Ibid*. at 2-3.

[330] *Report of the Scientific and Technical Subcommittee on its Forty-Third Session*, UN COPUOS, UN Doc. A/AC.105/869, 2006 at 19, 39.

[331] *Addendum to the Report of the Committee on the Peaceful Uses of Outer Space*, UN COPUOS, UN Doc. A/AC.105/L.202/Add.4, 1993.

[332] *Report of the Legal Subcommittee on its Forty-Fourth Session*, UN COPUOS, UN Doc. A/AC.105/850, 2005 at paras. 141-42.

new agenda items.[333] Also, in 2002, France and other States proposed that the Legal Subcommittee immediately began to consider drafting principles on the prevention of orbital debris for adoption by the full General Assembly.[334] Such a proposal would be consistent with the subcommittee's recent practice, similar to the manner in which it handled issues concerning direct broadcasting, remote sensing, and nuclear power sources in outer space,[335] each of which ultimately became a set of principles adopted by the General Assembly.[336] Nevertheless, delegations that oppose adding orbital debris to the agenda declare that since the Scientific and Technical Subcommittee still has work to do on the orbital debris issue, it would be premature to start work on the subject in the Legal Subcommittee.[337]

F. Orbital Debris Practices of Other States and the ESA

Of course, the United States is not the only State concerned about the creation of orbital debris. The following discussion lists the highlights of the laws and technical practices of major space-faring States about which information was readily available in

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[333] *Report of the Legal Subcommittee on its Thirty-Fifth Session*, UN COPUOS, UN Doc. A/AC.105/639, 1996 at para. 54. In 1994, the full COPUOS suggested that the Legal Subcommittee modify its working methods to include "extensive open-ended informal consultations" on possible new agenda items. *Report of the Committee on the Peaceful Uses of Outer Space*, UN COPUOS, UN Doc. A/AC.105/607, 1995 at para. 160. This change brought several new topics up for discussion as potential agenda items, including orbital debris.

[334] UN COPUOS Legal Subcommittee, 41st Sess., 666th Mtg., UN Doc. COPUOS/LEGAL/T.666, 2002, online: <http://www.unoosa.org/pdf/reports/transcripts/legal/LEGALT_666E.pdf> [Transcript of 666th Mtg.]. France followed this up the next year with a proposed work plan for orbital debris based on the recently issued IADC Guidelines. *Work Plan on Space Debris*, UN COPUOS, UN Doc. A/AC.105/C.2/L.246, 2003.

[335] See the comments of Mr. V. Cassapoglou, the representative of Greece in Transcript of 666th Mtg., *supra* note 334 at 4.

[336] See *Principles Governing the Use by States of Artificial Earth Satellites for International Direct Television Broadcasting*, GA Res. 37/92, UN GAOR, UN Doc. A/37/92, 1982; *Principles Relating to Remote Sensing of the Earth from Outer Space*, GA Res. 41/65, UN GAOR, UN Doc. A/41/65, 1986; NPS Principles, *supra* note 199.

[337] *Report of the Legal Subcommittee on its Forty-Fourth Session*, *supra* note 332 at para. 142; *Research in the Russian Federation*, *supra* note 99 at paras. 28-29; *Report of the Scientific and Technical Subcommittee on its Thirty-Third Session*, UN COPUOS, UN Doc. A/AC.105/637, 1996 at 24.

English. It is by no means a comprehensive list of States with debris mitigation programs.

1. States

The Russian Federation's "Law on Space" contains a general provision prohibiting the creation of orbital debris.[338] The law declares the following activities are forbidden: "harmful pollution of space, leading to unfavorable environmental changes, including intentional destruction of space objects in space."[339] In 2000, the Russian Federal Space Agency adopted an orbital debris mitigation standard; a standard which will apply to the entire Russian Federation is currently being developed.[340] The standard includes items typical of the IADC Guidelines such as passivation and minimizing the release of operational objects.[341] Furthermore, the Russian Federation has a debris tracking system, second only to the SSN, and the Russian Federation also contributes to debris modeling and shielding efforts.[342]

Japan created an orbital debris mitigation standard in 1996 and applies it to the design and operation of spacecraft.[343] The standard address the areas of eliminating residual energy sources, relocating GEO satellites into higher orbits, deorbiting spacecraft from LEO, and minimizing the number of parts separated from spacecraft during normal

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[338] *Russian Federation Law on Space*, Sect. I, art. 4, para 2, reprinted in Edward A. Frankle, "International Regulation of Orbital Debris," (2001) *Proceedings of the Forty-third Colloquium on the Law of Outer Space* 369 at 378.
[339] *Ibid*.
[340] Kulik, *supra* note 100 at 14-15.
[341] *Ibid*.; *Research in Russian Federation*, *supra* note 99 at paras. 14-28.
[342] Kulik, *supra* note 100 at 14-15. The Russian Federation has approximately 21 sensors used for orbital debris research. *Ibid*. at 14.
[343] *National Research* February 2002, *supra* note 99 at para. 4.

operations.[344] Japan also formed a multi-agency orbital debris committee in 2000 to assist the Government of Japan and to provide input to COPUOS and the IADC.[345] In addition to its contribution to debris observation,[346] Japan also plays a role in the study of debris through its computer models and hypervelocity impact test facility.[347]

The United Kingdom adopted its Outer Space Act in 1986, which requires a license to launch a satellite, operate a satellite, or perform any activity in space.[348] A licensee may be required to "prevent the contamination of outer space" and to "avoid interference with the activities of others."[349] These phrases have been interpreted by the licensing authority (the Secretary of State, acting through the British National Space Centre) to permit technical evaluations of the probability of a satellite's collision with other objects and its end-of-life disposal plan.[350] Orbital debris software modeling tools are used as an additional part of the license review process.[351] The UK also has a national orbital debris coordination group that meets annually and works closely with the European Space Agency.[352] Finally, the UK chairs a working group within the

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[344] *Ibid.* at para. 5; Jasentuliyana, "Space Debris," *supra* note 161 at 153.
[345] *National Research* February 2002, *supra* note 99 at paras. 1-2.
[346] See *supra* note 101 and accompanying text.
[347] Nakajima, *supra* note 101 at 19-21.
[348] *Outer Space Act 1986* (U.K.), 1986, c. 38, online: <http://www.unoosa.org/oosa/SpaceLaw/national/united_kingdom/outer_space_act_1986E.html>.
[349] *Ibid.* at s. 5.-(2).
[350] R. Crowther, R. Tremayne-Smith, & C. Martin, "Implementing Space Debris Mitigation Within the United Kingdom's Outer Space Act" in Dansey, *supra* note 13, 577 at 579.
[351] *National Research on Space Debris, Safety of Space Objects with Nuclear Power Sources on Board and Problems Relating to Their Collision with Space Debris*, UN COPUOS, UN Doc. A/AC.105/838, 2004 [*National Research*, 2004] at para. 24; Crowther, *supra* note 350 at 580-81.
[352] *National Research*, 2004, *supra* note 351 at paras. 3-4.

International Organization for Standardization (ISO) that is drafting standards for orbital debris mitigation.[353]

In the 1990s, France imposed strict national mitigation measures for launches. The basic rule was that a launch should leave not more than one piece of passivated debris in orbit per payload.[354] Additional requirements were to eliminate all other debris during the design or operation of the launch system.[355] In October 2004, France took another step forward by becoming the first, and so far the only, ESA State to adopt the European Code of Conduct,[356] which is discussed in the Part IV.F.2 below.

Information about the debris mitigation measures of other States is less well published and less easily accessible. Nevertheless, it is significant that no State has publicly adopted a practice inconsistent with the IADC Guidelines or other debris mitigation measures. This state practice is an important component for the formation of a new international norm. Nevertheless, because of the lack of *opinio juris,* the emerging norm is not yet a binding obligation.[357]

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[353] *Ibid*. at para. 25. For additional information about the work of the ISO, see *infra* notes 413-420 and accompanying text.

[354] *Scientific and Technical Presentations to the Scientific and Technical Subcommittee at Its Thirty-Fifth Session,* UN COPUOS, UN Doc. A/AC.105/699, 1998 at 7.

[355] *Ibid*.

[356] Centre National d'Etudes Spatiales, *Code of Conduct for Space Debris Mitigation*, CNES Press Release PR61-2004, online: <http://www.cnes.fr/html/_455_465_3018_.php>; European Space Agency, *Space Debris Mitigation: The Case for a Code of Conduct*, online: <http://www.esa.int/SPECIALS/ESOC/SEMZPBW797E_0.html>.

[357] See *supra* notes 235-236 and accompanying text.

2. European Space Agency

The ESA operates a Network of Centres that work together to coordinate orbital debris efforts in Europe.[358] The ESA concern with orbital debris dates back to 1986 when a task force was formed to study the issue and published a report in 1988.[359] The ESA's work culminated in a 2004 European Code of Conduct for Debris Mitigation.[360] Although thus far the European Code has only been adopted by France, it will become effective once other member agencies of the ESA approve it.[361]

The European Code is based upon the IADC Guidelines, but contains additional details and explanations.[362] The European Code consists of 12 design guidelines and eight operational guidelines that all ESA members should follow in order to mitigate orbital debris. Each of the guidelines falls into one of four categories: prevention, end-of-life, impact protection, and re-entry safety measures.[363] The specific design and operational parameters established by the IADC Guidelines are notably similar to the IADC and US policies.

G. Nuclear Power Sources in Space

Because of the extra risk inherent in using radioactive materials in space as a power source, the UN General Assembly adopted a set of principles specifically

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[358] *National Research* December 2003, *supra* note 99 at 3. The network includes four space agencies: the British National Space Centre (BNSC), CNES of France, the German Aerospace Center (DLR) and ESA. *Ibid*.

[359] European Space Agency, *European Space Operations Centre: Focal Point for ESA Space Debris Activities*, online: <http://www.esa.int/SPECIALS/ESOC/SEMU2CW4QWD_0.html>. For the 1988 report, see European Space Agency, *Space Debris: A Report from the ESA Space Debris Working Group*, ESA SP-1109 (Noordwijk, The Netherlands: ESA Publications Division, 1988).

[360] *European Code of Conduct for Debris Mitigation*, Issue 1.0, 2004, online: <http://www.stimson.org/wos/pdf/eurocode.pdf>.

[361] *Ibid*. at ii.

[362] *Ibid.*

[363] *Ibid*. at iii.

addressing that problem. The 1992 NPS Principles are primarily designed to protect Earth's environment, rather than the outer space environment. They do so by establishing guidelines that apply in space and therefore the NPS Principles play a small role in mitigating orbital debris.

The goal of the NPS Principles is to limit that amount of radioactive material put into space by limiting the use of radioactive materials to those missions that cannot reasonably be operated using non-nuclear energy sources.[364] The NPS Principles declare that nuclear reactors and radioisotope generators should only be used on interplanetary missions, in "sufficiently high" Earth orbit, or in LEO if the satellite has a "highly reliable operational system" to transfer the satellite to a "sufficiently high" storage orbit.[365] A sufficiently high orbit is defined as one which allows the nuclear material to naturally decay, and therefore no longer be radioactive, before the satellite falls back to Earth.[366] The orbit should also "be such that the risks to existing and future outer space missions and of collision with outer space objects are kept to a minimum."[367] The only permitted fuel source for a nuclear reactor is highly enriched uranium-235.[368] Since the half-life of uranium-235 is more than 700,000 years,[369] the sufficiently high orbit will probably have to be near GEO to comply with the NPS Principles.

V. Analysis of Existing Legal and Technical Regimes

Quantifying the level of success of existing technical mitigation measures is difficult to do. For the legal regimes, only a rough qualitative assessment is possible.

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[364] NPS Principles, *supra* note 199 at princ. 3.
[365] *Ibid*. at princ. 3(2)(a) and (f).
[366] *Ibid.* at princ. 3(2)(b).
[367] *Ibid*.
[368] *Ibid*. at princ. 3(2)(c).
[369] Johnson, *Space Debris*, *supra* note 79 at 93.

This Part considers the effectiveness of the existing regimes, reaching the conclusion that while the technical solutions are adequate, the legal mechanisms need improvement.

A. Technical Solutions

Are the current IADC and national orbital debris mitigation regimes working? Does more need to be done? These questions are difficult to answer as there is not a comprehensive study on the effectiveness of the technical solutions and there are no agreed upon measures of merit. But the mitigation measures are obviously helping to alleviate the debris problem. For example, a 2004 NASA report on the history of satellite fragmentations concluded "[t]he lack of a significant increase [in orbital debris in recent years] is due both to higher Solar activity and the implementation of debris mitigation measures on the part of launching agencies and organizations."[370] Furthermore, despite the increase in the total number of new trackable pieces of debris each year, since the late 1990s, the annual rate of new debris created has decreased.[371]

Examining the amount of debris on a continuum, however, does not provide an accurate assessment of the effectiveness of mitigation measures. A recent attempt at quantifying technical success shows how difficult this analysis can be.[372] Each category of debris must be separately analyzed because different mitigation measures are applicable. This study, by Nicholas L. Johnson, the Chief Scientist and Program Manager of the NASA Orbital Debris Program Office, concludes that debris mitigation efforts have started to show "a beneficial effect on the accumulation of" operational

[370] NASA, *History of Fragmentations*, *supra* note 77 at i.
[371] Space Security.org, *supra* note 87 at 3-4.
[372] Johnson, "Historical Effectiveness," *supra* note 76 at 6-9.

debris such as rocket bodies and mission-related debris."[373] Without such efforts, the current debris problem would undoubtedly be much worse.[374] For payloads, the mitigation measures have not been in effect long enough to produce tangible results, although if satellite operators follow the general mitigation guidelines of reducing the orbital lifetime of inactive LEO satellites to 25 years, the debris population of this category will start to decrease in about another decade.[375] Fragmentation debris, although the most difficult category to assess, is still increasing according to Johnson.[376]

Another study predicts that end-of-life passivation efforts alone could reduce the amount of LEO debris by 50 percent over the next 100 years (as compared to a scenario in which no space objects used passivation measures).[377] If, in addition to passivation measures, all LEO satellites are deorbited within 25 years, the amount of debris in LEO can be reduced by more than 500 percent, when compared to a business-as-usual scenario.[378]

Even if the measures are gauged to be effective, the existing debris situation in some areas is so severe, that the long term situation is not optimistic. To comprehend how serious the situation has become, consider what Johnson wrote in a 1987 book:

> The state of space debris today should not be viewed apocalyptically. By all accounts space debris today does not pose a significant long-term

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[373] *Ibid*. at 9.
[374] *Ibid*.
[375] *Ibid*. at 6-7.
[376] *Ibid*. at 9. That is not to say, however, that the news is all bad. The intensity of breakups (as measured by breakups that create 100 or more pieces of trackable debris) have declined since 1991 as have the longevity of the debris clouds created during breakups. *Ibid*. at 8.
[377] Heiner Klinkrad, *Space Debris Models and Risk Analysis* (Chichester, UK: Praxis Publishing Ltd, 2006) at 169 [Klinkrad, *Models and Risk*].
[378] *Ibid*. at 182-3.

> hazard to operations in space. . . . [However] if we wait until serious side effects of space debris manifest themselves, we may be too late.[379]

with a 2006 article he co-authored, in which he concluded:

> The current debris population in the LEO region has reached the point where the environment is unstable and collisions will become the most dominant debris-generating mechanism in the future. . . . Only remediation of the near-Earth environment—the removal of existing large objects from orbit—can prevent future problems for research in and commercialization of space."[380]

B. Legal Regime

Legal solutions to the problem of orbital debris will always be technical in nature.[381] The most that the rule of law can do is permit, encourage, or mandate (with or without punitive consequences) certain technical procedures designed to mitigate orbital debris. Thus, the law is only the means to implement the real solution. This is no different than solutions to other environmental problems. For example, the US and many other States establish maximum levels at which certain contaminants can be found in the soil, water, or air. Factories are required to reduce emissions by certain amounts to comply with the standards; polluting entities pay fines and/or the costs of remediation. These technical solutions to more traditional environmental problems are implemented through legislation or administrative regulation. In the same way, if the problem of orbital debris is regulated by international principles or rules, those rules will be based upon technical standards.

The current legal regime governing objects in space (with the exception of the NPS Principles) was developed long before orbital debris was considered to pose any

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[379] Johnson, *Space Debris*, *supra* note 79 at 85.

[380] Liou, *supra* note 143 at 340.

[381] Accord, Galloway, *supra* note 316 at 253 ("Orbiting debris in space is a technical problem requiring scientific and engineering solutions realistically related to economic and political factors.")

hazard. Thus, no legal rules specifically designed to ameliorate the threats presented by orbital debris presently exist. The most that can be said is that existing international law permits States to implement debris mitigation measures.[382] It is, in fact, the *lacunae* concerning orbital debris in international law which critics identify as the main problem. Some of the most significant and frequently criticized examples of these *lacunae* are discussed in the following sections.

1. Satellite Registration

One area that could use improvement is the process of satellite registration. The Registration Convention requires very little information and it does not establish a time period during which the information must be provided.[383] Furthermore, there is no requirement to separately identify each space object in orbit, only those that are on a State's national registry.[384] This means, for example, that there is no requirement for a State to include rocket upper stages or fragmentation debris on the UN registry.[385] The Registration Convention permits, but does not require, updates about space objects on the registry.[386] Therefore, information quickly becomes obsolete. Looking at the UN registry, it is impossible to identify the location of any space object based on the data

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[382] Under international law, that which is not expressly prohibited in international law is generally permitted. See *Case of the S.S. "Lotus" (France v. Turkey)* (1927) P.C.I.J. (Ser. A) No. 10 at 18-19 (stating that "[r]estrictions upon the independence of States cannot . . . be presumed" and that international law gives States "a wide measure of discretion which is only limited in certain cases by prohibitive rules").

[383] Specifically, Article IV(1) requires "as soon as practicable" only the name of the launching State, the object's designator, the date and location of the launch, the general function of the object, and basic orbital parameters. Registration Convention, *supra* note 184.

[384] *Ibid*.

[385] Although not required, France has, as a matter of policy, decided to record all of its space objects, including fragmentation debris on both its national registry and the UN registry. Jean-Yves Trebaol, "French Policy and Practices for the Registration of Space Objects" in Dansey, *supra* note 13, 583 at 584.

[386] Registration Convention, *supra* note 184 at art. IV(2). States are encouraged, however, to provide information about objects that are no longer in Earth orbit. *Ibid*. at art. IV(3).

provided, to determine whether an object is still functional, or even to gather a complete list of all objects launched by a particular State. The UN registry could be computerized, but without a continual reporting requirement, it will always be obsolete. It is possible to achieve these reforms and still allow States to withhold (or provide little) information about sensitive national security satellites. These reforms would not only assist in identifying orbital debris, but could also be useful in resolving disputes under the Liability Convention.

2. Protection of the Space Environment Per Se

The lack of explicit, meaningful protection of the space environment is another common criticism. Article IX of the Outer Space Treaty prohibits harmful contamination, but only in a general, unenforceable way.[387] Article IX is impractical because it lacks both specificity and mechanisms for dispute resolution.[388] An additional critique of this provision is that it while it could be applied to unusually hazardous activities, the real threat to the space environment is from the cumulative effects of "normal, accepted space activities."[389] Moreover, the Liability Convention cannot be used as a mechanism for enforcing Article IX of the Outer Space Treaty. Although the Liability Convention does provide a negligence-based recovery system for damage in outer space, it only applies to space objects damaged in space and not to the space environment itself.[390]

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[387] See *supra* notes 204-205 and accompanying text.

[388] Raymond T. Swenson, "Pollution of the Extraterrestrial Environment" (1985) 25 A.F. L. Rev. 70 at 79. "Article IX is self-judging, self-imposed, and self-policed." *Ibid*. at 78 (quoting Dembling and Kalsi, "Pollution of Man's Last Frontier: Adequacy of Present Space Environmental Law in Preserving the Resource of Outer Space" 20 Netherlands Int'l L. Rev. 125 at 141).

[389] *Ibid*. at 79.

[390] *Ibid*.

3. Liability Convention

Like the other space law treaties, the Liability Convention's rules do not help regulate orbital debris. Although after-the-fact liability rules can create incentives to mitigate orbital debris, they would never create an obligation to do so. States may just ignore the rules and assume the financial risks. Thus, liability rules are a poor substitute for preventative rules.[391] For liability rules to have a noticeable effect on orbital debris, the rules must be enforceable and unambiguous. The Liability Convention's rules concerning damage in space are not intended to protect the space environment and therefore do not serve as a deterrent to the creation of orbital debris. There are three reasons why this is so.

The first is the problem of identification of the cause of damage. Due to the ratio of small, uncataloged debris to large, trackable debris, collisions in space are likely to be the result of debris which is too small to be traced. Thus, the operator of an injured satellite will not know which States were launching States and cannot pursue a claim under the Liability Convention.

Second, the claimant State must prove negligence on the part of the other State. Outer space is open to all States, and with the exception of GEO orbital slots, a State can put a satellite wherever it wants. Except for minor station-keeping maneuvers, deciding on the orbital parameters is the last affirmative act that a State takes. Merely placing a satellite into a particular orbit cannot be construed as negligence. Therefore, when a collision occurs decades later between objects from different States, what could the

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[391] *Ibid*. at 80.

claimant State identify as the negligent act?[392] Until recently it would have been nearly impossible to prove negligence.

There are a few scenarios, however, where it may be possible to establish negligence.[393] The IADC (and possibly the proposed UN General Assembly) mitigation measures could provide the legal standard for establishing negligence for a claim under the Liability Convention.[394] Although these technical measures are not intended to create a binding international norm, a creative claimant State would not be precluded from arguing that failure to comply with the accepted mitigation standards is still evidence of negligence. Thus, in the case of a collision between an inactive payload and an active satellite, the claimant State could argue that failure to remove the object from Earth's orbit or to put it in a disposal orbit was a negligent act.[395] A claimant State could make a similar argument if the damage was caused by operational debris which could have been avoided by complying with the IADC guidelines.

Third, a State seeking compensation must still establish causation. With two objects moving around Earth bound only by the laws of physics and not "rules of the road," which object caused the collision?[396] Both States can legitimately claim that the

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[392] *Ibid*.

[393] These hypotheticals assume the claimant State can identify the launching State of the debris.

[394] Under the Liability Convention, claims are presented to the appropriate launching State through diplomatic channels. Liability Convention, *supra* note 211 at art. IX. If the States cannot settle the claim within one year, they must jointly establish a Claims Commission at the request of either party. *Ibid*. at art. XIV.

[395] Of course, such an argument would only be effective for satellites launched after the IADC Guidelines were created.

[396] Satellites in GEO are allocated specific locations by the ITU, which could be considered to be "rules of the road." See *supra* note 40 and accompanying text. In this respect, GEO is different from other areas of space. Nevertheless, satellites there must still maneuver to maintain position. Establishing which of two maneuvering satellites caused damage could still be difficult, although it would not be as difficult as the nearly impossible task of proving causation in LEO.

other State's object caused the collision.[397] Even in the scenarios in which it may be possible to establish negligence, causation will still be a difficult hurdle, especially since functional satellites are probably capable of maneuvering to avoid the debris. A State defending itself in an action brought under the Liability Convention could argue that the claimant State's failure to maneuver was contributory negligence, offsetting any negligence by the respondent State. This counter-argument is also made possible by recent events—the creation of a free, publicly available software tool that identifies potential collisions.[398]

Since it will usually be impossible to prove identity, negligence, and causation, the Liability Convention is ineffective at preventing orbital debris and in providing redress for the damages caused by orbital debris.[399]

4. Remediation

Another potential problem with the current legal regime concerns remediation, or clean up, of the space environment. Currently, there are no economically or technically feasible ways to remove debris from space. But even if there were, the existing rules of space law would present a major obstacle. To have any noticeable effect on the quantity

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[397] Swenson, *supra* note 388 at 80.

[398] See *supra* notes 114-116 and accompanying text.

[399] This analysis and these examples show the difficulty of creating international rules that are designed for space, an environment unlike any on Earth. Even in a more familiar environment (the high seas) and with existing "rules of the road," determining compensation due from collisions is complex because of many factors, not the least of which is the differences in concepts of tort between common law and civil law jurisdictions. See William Tetley, "Division of Collision Damages: Common Law, Civil Law, Maritime Law and Conflicts of Law" (1992) 16 Tul. Mar. L. J. 263 (discussing application of Brussels Convention of 1910 for maritime collisions); James P. Lampertius, "The Need for an Effective Liability Régime for Damage Caused by Debris in Outer Space" (1992) 13 Mich. J. Int'l L. 447 at 457 note 74 (commenting on need for rules of space navigation analogous to rules of maritime navigation). Given the problems of applying maritime rules, which have a long history and many cases forming a basis of comparison, it is no surprise that creating a new regime in outer space has been so complex and difficult.

of debris, a group of States undertaking such an endeavor would need to be able to remove any debris, not just debris for which that group of States was a launching State.[400] However, under the Outer Space Treaty and the Registration Convention, only a launching State can have jurisdiction and control over its space objects.[401] Therefore, no State can remove or change the orbit of any space objects for which it is not the launching State and State of registry; at least, not without authorization from the State of registry.[402] Therefore, this rule in Article VIII of the Outer Space Treaty has been criticized as an impediment to proposed solutions for the orbital debris problem.[403] To be fair, however, this is not really a legitimate criticism because the technology is unavailable.

5. Mandatory Technical Regulations

There are no internationally binding technical rules concerning debris mitigation measures, and States have expressly disavowed their intent to create any such rules through the Scientific and Technical Subcommittee of COPUOS.[404] Although guidelines do exist through the IADC, they are merely suggestions and States are not compelled to comply. If any binding mitigation rules are to be created, that process will begin with the Legal Subcommittee, which has yet to add the discussion to its agenda.[405] If the Legal

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[400] Consider the concept of having a satellite rendezvous with multiple pieces of orbital debris discussed in Part II.E, above. For this type of operation to be cost-effective, debris in similar altitudes and inclinations would need to be targeted, irrespective of jurisdiction and control over that debris.

[401] Outer Space Treaty, *supra* note 201 at art. VIII; Registration Convention, *supra* note 211 at art. II.

[402] For space objects which are not registered by any State, no one could possibly object. Thus, the problem will only exist for registered objects.

[403] E. Gordon, "Toward International Control of the Problem of Space Debris" (1982) *Proceedings of the Twenty-Fifth Colloquium on the Law of Outer Space* 63 at 64.

[404] See *supra* note 329 and accompanying text.

[405] The subcommittee's 2006 report made clear that it would wait at least one more year on the outcome of the Scientific and Technical Subcommittee before beginning consideration of the issue of orbital

Subcommittee does act to create a set of rules, based on recent experience, the outcome will most likely be a set of principles forwarded to the UN General Assembly for action. UN principles, however, are generally not binding law.

Under the Charter of the United Nations, the General Assembly only makes recommendations and lacks the power to act as a legislature to create new law.[406] On the other hand, the International Court of Justice (ICJ) and other international tribunals have noted that "certain resolutions, whether they have strict legislative character or not, are expressions of law and carry with them obligations in the juridical sense."[407] For example, the ICJ has stated:

> General Assembly resolutions, even if they are not binding, may sometimes have normative value. They can, in certain circumstances, provide evidence important for establishing the existence of a rule or the emergence of an *opinio juris*. To establish whether this is true of a given General Assembly resolution, it is necessary to look at its content and the conditions of its adoption; it is also necessary to see whether an *opinio juris* exists as to its normative character. Or a series of resolutions may show the gradual evolution of the *opinio juris* required for the establishment of a new rule.[408]

Commentators have also observed that to determine whether the provisions of a particular resolution reflect international law, many factors must be considered, the most important of which are the terms of the resolution and the States' intent, the voting patterns, and State practice.[409] In the context of orbital debris, it is doubtful that any of these factors would lead to the conclusion that principles announced by the UN General Assembly

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debris. *Report of the Legal Subcommittee on Its Forty-Fifth Session,* UN COPUOS, UN Doc. A/AC.105/871, 2006 at para. 150.

[406] *Charter of the United Nations* at art. 11.

[407] Jorge Castañenda, *Legal Effects of United Nations Resolutions*, translated by Alba Amoia (New York: Columbia University Press, 1969) at 6.

[408] *Legality of the Threat or Use of Nuclear Weapons, supra* note 181 at para. 70.

[409] Blaine Sloan, "General Assembly Resolutions Revisited" (1987) 58 B.Y.I.L. 39 at 126-38.

would be binding. A binding requirement on States to comply with orbital debris mitigation policies is unlikely to be implemented in the near future.

VI. Proposals for Change

This thesis concludes with a critical analysis of the suggestions for improvement in orbital debris mitigation measures that have been offered over the years. Although a variety of modifications to the existing legal regime are surveyed, they are all ultimately found to be unsatisfactory. Therefore, this thesis puts forth a new proposal for change for consideration by the legal community.

A. Solutions Proposed by Others

Over the past couple of decades, many legal commentators and scientific experts have written about orbital debris. The unanimous conclusion is that orbital debris is a problem that will continue to get worse absent technical and legal measures created specifically to target the problem. The international scientific community has generally come to a consensus about currently technical feasible solutions. The legal community, however, is far from uniform.

1. Technical Solutions

The scientific community's solutions are primarily expressed in the IADC Guidelines. The Guidelines are a recent development and represent the state-of-the-art in technically feasible solutions. Yet technology is constantly evolving and the solutions that are adequate today may be insufficient tomorrow or may be superseded by less-costly or more efficient technologies. Thus, the work of the IADC will continue and new solutions must continue to be evaluated.

For example, one technology that is being evaluated for LEO is a tether. The tether can be attached to a satellite prior to launch or placed on existing debris by a spacecraft that would have to be designed for that particular purpose. Tether are strands of material, several kilometers in length, which interact with Earth's ionosphere, causing the object's orbit to rapidly decay.[410] The advantage of the tether is that fuel does not need to be reserved for end-of-life deorbiting maneuvers.[411] The disadvantages are that (1) tethers are extremely fragile and if broken by existing orbital debris, they will create even more debris; (2) they increase the surface area of the satellite, increasing the likelihood of a collision with orbital debris; and (3) they are not controllable like a propulsion system. For these reasons, tethers are not a perfect solution and must be evaluated on a case-by-case basis.[412]

A future expression of technical solutions may be found in the standards documentation of the International Organization for Standardization (ISO). The ISO is a nongovernmental federation of the national standards organizations of 149 States and is the leading developer of international standards.[413] ISO standards are developed based

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[410] P. Krisko, "Progress in Space Tether Sever Modeling" (2005) 9:4 *Orbital Debris Quarterly News* 4, online: <http://www.orbitaldebris.jsc.nasa.gov/newsletter/pdfs/ODQNv9i4.pdf>. For example, a tether could reduce the deorbit time of a GlobalStar satellite from 11,000 years (for natural decay) to 46 days and an Iridium satellite's deorbit time from 100 years to 7.5 months. Klinkrad, *Models and Risk*, *supra* note 377 at 179. The effectiveness of a tether is dependent upon its length, the mass of the space object being deorbited, and the space object's altitude and orbital plane. *Ibid*. at 178-9.

[411] Nevertheless, there is still a mass penalty for attaching a tether to a satellite. See Part III.B above.

[412] *Support to the IADC Space Debris Mitigation Guidelines*, *supra* note 300 at 10-11. The probability that a tether will not complete its mission if used above 1,000 kilometers is such that tethers are generally not recommended for deorbiting procedures from above that altitude. C. Pardini *et al.*, "Assessing the Vulnerability to Debris Impacts of Electrodynamic Tethers During Typical De-Orbiting Missions" in Dansey, *supra* note 13, 353 at 359.

[413] William H. Ailor & Emma A. Taylor, "ISO Standards: The Next Step for Orbital Debris Mitigation" (Paper presented to the 56th International Astronautical Congress of the International Astronautical Federation, the International Academy of Astronautics, and the International Institute of Space Law, held in Fukuoka, Japan, 17-21 October 2005), IAC-05-B6.3.09 [unpublished] at 2.

upon input from industry and States.[414] ISO standards are voluntary, but are frequently used throughout private industry and government.[415]

The Space Systems and Operations Sub-Committee of the ISO's Aircraft and Space Vehicles Technical Committee (known as ISO TC20/SC14) formed an Orbital Debris Coordination Working Group (ODCWG) in 2003.[416] The ODCWG is tasked with developing a plan for the preparation of ISO standards implementing orbital debris mitigation and maintaining liaisons with agencies such as the IADC and COPUOS.[417] The first ISO debris standards are not expected until 2008 and additional elaborations of the standards will likely follow in subsequent years.[418] The ODCWG has encountered some difficulty in its work since there is little or no industry best practices concerning debris mitigation.[419] The ODCWG is currently evaluating proposals for standards in the following areas: mitigating orbital debris, disposing of GEO satellites, measuring remaining propellant, estimating reentry hazards, avoiding collisions during the launch and orbital insertion phases, and communicating standardized information about satellite orbits.[420] The ISO standards are unlikely to break new ground beyond what is already contained in the IADC Guidelines, but they should assist the space industry in understanding and complying with the Guidelines.

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[414] *Ibid.* at 3.
[415] *Ibid*.
[416] John Davey & Emma A. Taylor, "Development of ISO Standards Addressing Mitigation of Orbital Debris" in Dansey, *supra* note 13 at 565.
[417] *Ibid*. at 566.
[418] Ailor, *supra* note 413 at 3.
[419] Davey, *supra* note 416 at 568.
[420] Ailor, *supra* note 413 at 3-4.

2. Legal Solutions

The following discussion is a brief survey of some of the proposed changes to the existing law of space described by commentators.[421] The most radical proposals call for a complete scrapping of the current space law treaties and principles and starting over with one comprehensive treaty that would be updated to account not only for orbital debris, but for all other changes since the original treaties, such as the increase of commercial entities in space.[422] Another proposal, also concerning issues broader than the topic of orbital debris but which nonetheless would affect it, suggests that the liability rules should be modified to eradicate or at least unify private international law.[423]

a) Modifications to Liability Regime

Turning to proposals which are narrowly focused on the topic of orbital debris, the most frequently mentioned ideas are (1) to create a damage compensation fund,[424] (2) to apportion damages based on a theory of market-share liability,[425] and (3) to modify the fault-based standard for damages in space.[426]

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[421] The citations in this Part are not necessarily solutions advocated by the cited author. In some cases, the authors were also surveying the literature and referencing the ideas of others.

[422] For example, see Cheng, *supra* note 10 at 641-67; Mimi Lytje, "Obstacles on the Way to a General Convention" (2005) *Proceedings of the Forty-Seventh Colloquium on the Law of Outer Space* 267 at 271. Some States have called for the creation of an updated comprehensive space law treaty during discussions of the COPUOS Legal Subcommittee. *Report of the Legal Subcommittee on Its Forty-Fifth Session*, *supra* note 405 at para. 45. Predictably, other States responded that such a treaty was neither necessary nor wise. *Ibid* at paras. 47-48.

[423] Dimitri Maniatis, "The Law Governing Liability for Damage Caused by Space Objects: From State Responsibility to Private Liability" (1997) 22:1 Ann. Air & Sp. L. 369 at 399-400.

[424] See Roberts, "Liability Regimes," *supra* note 205 at 69-71; Swenson, *supra* note 388 at 86; Williams, *supra* note 227 at 1188; Limperis, *supra* note 139 at 336-7; Mark J. Sundahl, "Unidentified Orbital Debris: The Case for a Market-Share Liability Regime" (2000) 24 Hastings Int'l & Comp. L. Rev. 125 at 137-8.

[425] See Glenn H. Reynolds & Robert P. Merges**,** *Outer Space: Problems of Law and Policy* (Boulder, CO: Westview Press, 1997) at 189; Allen Rostron, "Beyond Market Share Liability: A Theory of Proportional Share Liability for Nonfungible Products" (2004) 52 UCLA L. Rev. 151 at 200-202 (suggesting the concept is more correctly labeled proportionate share liability); Limperis, *supra* note 139 at 339-41; Sundahl, *supra* note 424 at 138-54. The idea for market-share liability was originally

These three proposals have been suggested so often that a brief comment on their merits is warranted, beginning with market-share liability. There are several reasons why a market-share liability regime will not work in outer space. First, in space the pool of potential claimants is the same as the pool of potential respondents. In the usual market-share liability regime, a group of manufacturers create a fungible product that causes injury to persons or property, but the manufacturers themselves will never be a plaintiff. Under the law governing the use of space, all rights and responsibilities flow through States, not private entities, making the States both the claimants and respondents. To illustrate how this presents a problem for a market-share liability, consider the following hypothetical: iIn unrelated events, both a US satellite and an Indian satellite, each valued at $5 million, are destroyed by unidentified debris. The US is responsible for about 42 percent of the total amount of orbital debris and India for about 1.5 percent.[427] Under the market-share regime, the US could only recover $2.9 million for the value of its satellite (since the US would be responsible for bearing 42 percent of its own loss) but at the same time would have to pay $2.1 million for the US share of the Indian satellite. India, on the other hand, would only have to pay $75,000 for its share of the damage to the US satellite and would recover $4.9 million for its own satellite.[428] Thus, a claimant's damages will always be offset by the proportion of debris for which it is responsible, defeating the purpose of the market-share regime.

proposed by Reynolds and Merges in 1989 and has recently "enjoyed a resurgence in space debris scholarship." *Ibid*. 138-9.

[426] Baker, *Space Debris*, *supra* note 41 at 86-7; Swenson, *supra* note 388 at 86; Lampertius, *supra* note 399 at 464-5; Limperis, *supra* note 139 at 338-9.

[427] Cataloged Objects, *supra* note 66 at 10.

[428] The issue of currency conversion is not addressed in this scenario, but in a world-wide market-share regime could become a substantial issue. See *e.g.* Liability Convention, *supra* note 211 at art. XIII.

A second problem is identifying the proportion of debris for which each State is responsible. This is why the market-share liability regime developed in the first place. The theory was first applied to manufacturers of a synthetic form of estrogen.[429] Because the substance was fungible, pharmacists routinely filled prescriptions for it from any of the many manufacturers.[430] Thus, the plaintiffs were unable to identify any one company which caused the harm to them. The California courts created a new theory of liability, premised upon the idea that each manufacturer would be liable in proportion to its share of the market.[431] Market share for pharmaceutical companies is relatively easy to determine based upon financial records. Orbital debris is much more complicated. Since the theory will only be applied to damage caused by unidentified debris,[432] what is the best way to create liability for an unknown quantity? The most plausible answer is to determine liability based on the known, trackable debris,[433] but this is not a satisfactory solution.

There may not be a relationship between the amount of known and unknown debris created from a satellite breakup.[434] For example, a rocket stage that explodes may create three pieces of trackable debris and 1,000 pieces of small debris or it could create 500 pieces of trackable debris and 1,000 pieces of small debris. In the latter case, the launching State would be held disproportionately liable under a market-share liability

[429] Sundahl, *supra* note 424 at 139.
[430] *Ibid*.
[431] *Ibid*. at 141.
[432] For damage caused by debris that can be identified with a particular launch, the respondent States are known and market-share theories are inapplicable.
[433] Sundahl, *supra* note 424 at 145-6.
[434] Rostron, *supra* note 425 at 201.

system, without regard to fault or the due care they exhibit.[435] The potential risk also varies with altitude. Debris at 900 kilometers altitude poses a much greater risk than debris in GEO. And perhaps most significantly, multiple States may be liable for each piece of debris. The SSN catalog identifies only one State responsible for each piece of debris. In reality, four or more States could be equally liable.[436] The proposed market-share regime fails to take these variables into account.

A third problem with the proposal is its failure to make an allowance for damage caused by natural orbital debris. For the market-share liability regime to apply, the identity of the object causing the damage must be unknown. Since the identity is not known, the debris is most likely small and untrackable, thus the possibility that natural debris (or for that matter, a malfunction unrelated to debris)[437] caused the damage cannot be ruled out. Compensation for damage that cannot be definitively associated with some type of artificial debris is well beyond strict liability. Such a proposal is more analogous to insurance for satellites underwritten by all States, primarily those States conducting the most launches. For all of these reasons, the proposal has no chance of being accepted by either the US or the Russian Federation. Without support from all the major space-faring nations, a market-share liability regime will never succeed.

Proposals for a compensation fund suffer from similar shortcomings. A damage compensation fund would pay for damage to satellites from unidentified debris.

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[435] The amount of debris created by different types of breakups varies. For example, eight Delta second stage explosions created an average of 198 pieces of trackable debris each whereas 12 Ariane rocket stages created only 50 pieces of trackable debris on average. NASA, *History of Fragmentations*, *supra* note 77 at 11-16.

[436] See Liability Convention, *supra* note 211 at art. V(1) (concerning joint and several liability for States jointly launching space objects).

[437] It is seldom possible to know the exact cause of a satellite's malfunction unless it collides with trackable debris. Selding, *supra* note 132.

Essentially, these proposals all attempt to correlate the amount of money a State will have to pay into the fund with the amount of debris created.[438] Suggestions for how to infuse cash into the compensation fund include basing a State's contributions on the debris-creating potential of the satellite,[439] a set amount per launch,[440] or a set percentage of the launch cost.[441] In order to quickly fill the coffers of the proposed fund, States that were active in space in the past (the US and USSR primarily) might have to make catch-up payments based on older orbital debris.[442]

Such a fund would be punitive in the sense that it would discourage the creation of new orbital debris through a fine or a tax. Once created, the fund would essentially be insurance for satellites against damage caused by unidentified debris. Space-faring States would likely be unwilling to enter into such an arrangement. With private insurance for satellites readily available on the market, few States would see it as being in their best interest to create their own system of insurance. Another problem is maintaining the funding at an adequate level to pay out claims. At least the market-share system would only require States to pay as damage actually occurs. The proposals for funds would have to balance the amount of revenue needed to offset potential claims; this would be a very difficult task. Finally, this proposal has the potential to permit fraud. A dishonest State could place a self-destruct device on a satellite. Near the end of the satellite's useful life, the State could destroy it and claim reimbursement from the fund.

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[438] In contrast, a market-share liability regime or a modified fault-based liability system would not require an existing fund.

[439] Roberts, "Liability Regimes," *supra* note 205 at 70.

[440] Limperis, *supra* note 139 at 336-7.

[441] Frans G. Von der Dunk, "The 1972 Liability Convention – Enhancing Adherence and Effective Application" (1999) *Proceedings of the Forty-First Colloquium on the Law of Outer Space* 366 at 369.

[442] Roberts, "Liability Regimes," *supra* note 205 at 70.

The desire by some commentators to "punish" States for creating orbital debris through taxes or fines is understandable. However, for such a system to have a chance at being accepted by the international community, the revenue created through such a system would have to be put to some other use, such as orbital debris research or funding an international orbital debris tracking organization.[443] Even then, international acceptance of this idea is unlikely.

Finally, commentators have suggested a number of improvements to the current fault-based standard applicable to damage occurring in outer space. Some commentators suggest a shift to strict liability, arguing that a fault-based regime is unworkable or unjust when the damage is caused by orbital debris.[444] Others advocate a modified fault-based liability.[445] For example, under such a system, a State would be presumed liable for damage caused by its space object if the State failed to use disposal orbits or other mitigation measures.[446] One commentator has even gone as far as asserting that creating any orbital debris is negligence per se.[447] These more moderate proposals have some merit. Shifting the burden of proof of negligence to debris-creating States seems appropriate, especially considering the difficultly claimant States will have in proving negligence. But small changes to liability rules alone will not be sufficient to curb the problem of orbital debris; preventative rules are also needed.

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[443] See Limperis, *supra* note 139 at 337.
[444] Baker, *Space Debris*, *supra* note 41 at 86-7.
[445] See Lampertius, *supra* note 399 at 464.
[446] *Ibid*.
[447] *Ibid*.

b) Other Substantive Proposals

Various other proposals have surfaced over the years from a variety of commentators. Some authors propose an environmental regulatory regime that would mandate an environmental impact analysis for each launch.[448] These plans call for the international adoption of rules similar to the US National Environmental Policy Act (NEPA).[449] The problem with such a rule is enforcement. In order for an environmental impact analysis to have any meaning, there must be an enforcement mechanism, otherwise it is self-policing and will be ineffective.[450]

Other commentators are concerned about enshrining technical mitigation rules in a treaty because treaties are generally inflexible and cannot adapt quickly to changing technology. Thus, some seek the treaty-based creation of a regulatory body that can flexibly adapt to more advanced mitigation measures, similar to the structure of the International Civil Aviation Organization (ICAO).[451] Another treaty-based idea is less ambitious as it merely endeavors to codify rules requiring States to cooperate with one another to prevent orbital debris and to inform, consult, and negotiate with other States concerning debris issues.[452] Other proposals would also require either a new treaty or

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[448] See Bruce L. McDermott, "Outer Space: The Last Polluted Frontier" (1992) 36 A.F. L. Rev. 143 at 158; David E. Reibel, "Environmental Regulation of Space Activity: The Case of Orbital Debris" (1991) 19 Stan. Envtl. L.J. 97 at 134-5; Swenson, *supra* note 388 at 84-5.

[449] 42 U.S.C. § 4321. See Reibel, *supra* note 448 at 117-25.

[450] See *supra* note 388 and accompanying text. NEPA has been criticized for the same reasons. See Wendy B. Davis, "The Fox is Guarding the Henhouse: Enhancing the Role of the EPA in FONSI Determinations Pursuant to NEPA" (2006) 39 Akron L. Rev. 35. The primary enforcement mechanism for NEPA is lawsuits brought by US citizens or environmental groups, which are largely ineffective. *Ibid*. at 43. A similar enforcement mechanism in international law would be even less effective because of the reluctance of States to permit claims against them.

[451] See Howard A. Baker, "Space Debris: Law and Policy in the United States" (1989) 60 U. Colo. L. Rev. 55 at 88-9; Jasentuliyana, "Space Debris," *supra* note 161 at 160-62.

[452] See *International Instrument on the Protection of the Environment from Damage Caused by Space Debris*, Arts. 3-4, adopted by the 66th Conference of the International Law Association, Buenos Aires,

modifications to existing ones. One such example is permitting States to "disown" objects on a space registry which could then be moved or removed from space by any State.[453] To encourage this practice, a failure to disown a derelict object would be construed as automatic fault under the Liability Convention.[454] One commentator has even suggested that States should be required to remove nonfunctional satellites and any other State would be entitled to use self-help measures to enforce the rule.[455]

Another group of scholars propose solutions that avoid creating new treaties, instead preferring UN General Assembly principles, codes of conduct like the IADC Guidelines, or other informal and voluntary regimes.[456] A hybrid approach is suggested by others who propose beginning with an informal, voluntary ("soft law") rules and moving to a framework convention that would be amended by protocols as technical knowledge and political will permit.[457]

1994, reprinted in *Proceedings of the Workshop on Space Law in the Twenty-first Century*, U.N. Doc. A/CONF.184/7, 1999, 200 at 200-203. This proposed treaty could be viewed as an ineffective elaboration of the provisions of Article IX of the Outer Space Treaty. For an alternative orbital debris treaty proposal, see Pamela L. Meredity, "A Legal Regime for Orbital Debris: Elements of a Multilateral Treaty" in Simpson, *supra* note 170, 214 at 220-23.

[453] Cheng, *supra* note 10 at 506; Perek, "Management Issues," *supra* note 225 at 589 (arguing that removing legal obstacles could promote scientific research into methods for removal). But see Carl Q. Christol, "Protection Against Space Debris—The Worst Case Scenario" (2001) *Proceedings of the Forty-Third Colloquium on the Law of Outer Space* 346 at 350-5 (observing that international law already permits States to take unilateral protective action to remove orbital debris).

[454] *Ibid*.

[455] Swenson, *supra* note 388 at 84.

[456] See Steven A. Mirmina, "Reducing the Proliferation of Orbital Debris: Alternatives to a Legally Binding Instrument" (2005) 99 Am. J. Int'l L. 649 at 654-60; Gabriel Lafferranderie, *Commentary Paper* (presented to the Proceedings of the Workshop on Space Law in the Twenty-first Century held in Vienna, Austria, July 1999), U.N. Doc. A/CONF.184/7, 1999, 196 at 198. In addition to the political problems inherent in creating a new treaty, some authors believe creating a mandatory treaty regime on orbital debris will also discourage private investment in space. Smith, *supra* note 172 at 69-70.

[457] Tan, *supra* note 63 at 179-183 (noting that "[a]ny convention that attempts to impose hard obligations at the outset without taking into account the interests of the space powers will be condemned to obsolescence."). A critical part of this commentator's strategy would be the creation of an international space agency that would, *inter alia*, develop recommendations for the protocols. *Ibid*. at 192. See also Winfried Lang, "Environmental Treatymaking: Lessons Learned for Controlling Pollution of Outer Space" in Simpson, *supra* note 170, 165 at 178.

c) Procedural Proposals

A final commentator eschews the substantive debate on legal solutions and instead focuses on the best procedural methods that can bring about whatever substantive regime is appropriate. This staged approach begins with the mobilization of political and scientific interest among experts and encouraging developing nations to participate in the process.[458] The next stage is to utilize existing international space law norms.[459] Finally, there must be a process for evaluating proposed solutions to maximize their legitimacy and improve the likelihood of compliance.[460]

B. A New Proposal

States have responded to the scientific community's concern about orbital debris. The IADC Guidelines represent the solutions that are currently technically feasible and affordable yet still permit maximum use of outer space. Major space-faring States have implemented or are in the process of implementing their own national orbital debris mitigation policies or rules consistent with the IADC Guidelines. Thus, since the creation of the IADC, the focus of commentators has shifted from "broad pronouncements of liability and responsibility from an environmental perspective" to a discussion which is more "pragmatic."[461] Specifically, the shift has been away from *ex*

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[458] Robert C. Bird, "Procedural Challenges to Environmental Regulation of Space Debris" (2003) 40 Am. Bus. L.J. 635 at 645-52. Other commentators suggest that only the space-faring nations should be directly involved in treaty negotiations to avoid politicized, non-technical issues. See Jeffrey Maclure & William C. Bartley, "Orbital Debris: Prospects for International Cooperation" in Simpson, *supra* note 170, 201 at 202; Diane P. Wood, "Who Should Regulate the Space Environment: The Laissez-Faire, National and Multinational Options" in Simpson, *supra* note 170, 189 at 195.

[459] *Ibid*. at 653-64.

[460] *Ibid*. at 664-80. The drafters of the substantive proposal should also heed the lessons learned from failed treaty efforts. *Ibid*. at 681-4.

[461] E. Jason Steptoe, "Legal Standards for Orbital Debris Mitigation: A Way Forward" (2002) *Proceedings of the Forth-Fourth Colloquium on the Law of Outer Space* 301 at 303 (quoting Edward A. Frankle,

post facto punitive measures to proactive prevention by encouraging compliance with internationally adopted debris mitigation standards.[462]

A UN General Assembly resolution adopting orbital debris mitigation principles would reflect the strong desire by States to attack the problem and would be a good first step. But more can be done. The difficulty lies not in the desire to do something about the problem, but what form the solution should take.

For a legal (as opposed to technical) orbital debris mitigation regime to have any chance of being accepted by the international community, it must meet at least five criteria. First, there must be an exchange of rights and responsibilities. One-sided treaties in which one group of States gets all of the benefits and another group of States incurs all of the obligations have little chance of ratification. For example, the US is unlikely to ever ratify a treaty creating market-share liability since there would be few, if any, tangible benefits to the US. Second, a mitigation regime should not create specific technical rules in an inflexible treaty since technological capability changes more rapidly than traditional treaties can adapt. Third, the technical requirements should be expressed in terms of soft goals rather than hard requirements. For example, it is better to say that all GEO satellites should be relocated to a disposal orbit 300 kilometers above GEO rather than declare that all GEO satellites must maintain 2 percent of fuel reserves for relocating to a disposal orbit. Fourth, the treaty should avoid creating a new, permanent international organization such as ICAO because many States are adamantly opposed to creating new international bureaucracies. Finally, the new legal regime should be

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"International Regulation of Orbital Debris," (2001) *Proceedings of the Forty-third Colloquium on the Law of Outer Space* 369 at 377).

[462] *Ibid*.

voluntary since some States will not be willing to surrender so much of their sovereignty over their outer space activities. Bearing these concepts in mind, a treaty-based solution is attainable. The following discussion is one such solution with supporting rationale.

Minor revisions to existing treaties can accomplish the goal of helping to reduce the creation of new orbital debris.[463] First, the term "space object" must be defined to make clear that it applies to orbital debris. The definitions of orbital debris currently in the literature can serve as a beginning point for a discussion of the appropriate definition. Second, States should be encouraged to take "all appropriate measures" to reduce the creation of orbital debris. The phrase "all appropriate measures" should be defined within a technical annex that is reviewed on a regular basis and can be flexibly amended without requiring approval from all States party to the treaty.[464] The technical annex would be based upon the IADC Guidelines (or similar UN guidelines if they are ever approved). Third, States may, prior to any launch, submit technical documents concering the rocket and/or payload to an appropriate international organization.[465] The technical documents should contain sufficient information to indicate whether the rocket and payload conform to the treaty's technical annex.[466] The documents submitted by a State

[463] The revisions would need to be created through protocols so as not to disturb the existing regime. Any proposal to eliminate the current treaties is unlikely ever to be successful.

[464] This can be accomplished any number of ways. It could be modeled on the Radio Regulations of the ITU or it could take the form of a technical commission such as the one created by the Montreal Plastic Explosives Convention of 1991. See *Convention on the Marking of Plastic Explosives for the Purpose of Detection*, 1 March 1991, 2122 UNTS 359, 30 ILM. 721 at Arts. V-VIII. The precise method is unimportant, so long as the technical annex can be amended as needed.

[465] The treaty drafters will have to decide whether ICAO, COPUOS, or some other international organization is the most appropriate entity.

[466] If there will be more than one launching State, as defined in the Outer Space Treaty and the Liability Convention, a submission by one State would be deemed to be a submission by all the launching States.

would be available to the public and other States and would be kept on file in the event they are needed for future dispute resolution.

Fourth, in the event one State seeks compensation from another State under the Liability Convention for damage occurring in outer space, the fault rules to be applied will depend on whether the status of the space objects and whether the respondent State complied with the technical annex as it existed at the time of the launch. For collisions between two objects of debris, there would be no liability for either State. For collisions between two functional objects which are capable of maneuvering, the current negligence fault standard of the Liability Convention should apply. In reality, this would likely mean neither State would recover from the other due to the difficulty in proving negligence. However, if the respondent State's object was orbital debris and it failed to either submit technical documents prior to the launch or the documents fail to prove the object complied with the technical annex, then the respondent State will be strictly liable for damages to the claimant State's satellite.[467] Finally, if the respondent State's object did comply with the technical annex at the time of launch, then the respondent State will not be liable to the claimant State unless the claimant State can prove the respondent State operated the object with gross indifference to the potential orbital debris consequences.[468]

This proposal is a combination of incentives to voluntarily comply with flexible technical mitigation rules coupled with increased risk of liability for failure to comply. Some commentators may object that it is unacceptable for a State to avoid liability if

[467] The treaty would not be applicable to debris already in space prior to a State becoming a party to the treaty. The current fault-based rule of the Liability Convention would apply to pre-existing debris.

[468] For example, the operator would act grossly indifferent if it allocated reserve fuel for transfer to a disposal orbit, but elected to extend the satellite's mission rather than use the fuel to relocate.

debris for which that State is responsible causes damage in space. However, under the current fault-based standard, States are already essentially free from liability. Therefore, this would not be a real change. For this reason, encouraging States to reduce orbital debris is more important than establishing liability. Since this treaty should be an exchange of rights and responsibilities, creating strict liability for failure to comply with the treaty is a strong incentive for voluntary compliance.

The technical documents that will be provided to an appropriate international agency serve several functions. First, they are an incentive to comply with the mitigation rules since failure to supply documents makes a State strictly liable in the event its debris collides with an active satellite. Second, since they are open to inspection, they serve as verification of compliance with the terms of the treaty.[469] Third, they are a repository of easily available evidence. Since the proposed liability regime depends upon the design and operation of the satellite complying with mitigation measures, evidence of the State's level of compliance will be required. Furthermore, because collisions may not occur for tens or hundreds of years after a launch (if ever), a repository of supporting documentation will make the process of determining liability easier.

The success of the proposal depends, in large part, on the ability to identify a particular piece of debris and associate it with a launching State. To some extent, that is possible with the existing SSN. States should, however, continue to improve debris detection, tracking, and identification systems with a goal of creating a real-time computerized international database of debris.

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[469] States will want to avoid releasing classified or sensitive data (such as that protected by the export control rules of the US). If it is not possible to create documents that will comply with the treaty yet avoid releasing sensitive data, then the State may choose not to furnish documents for that particular launch. In that case, the State will assume the risk that it will later be held strictly liable.

VII. Conclusion

Orbital debris has become the most significant obstacle to the use and exploration of outer space. There are no quick fixes. Current technology limits us to mitigating the problem when remediation measures are really necessary. Presently, the major space-faring States have created voluntary mitigation measures and are generally complying with them. These have been helpful in preventing the creation of new debris, but better legal solutions are possible. The current *lacuna* of international law concerning orbital debris needs to be filled with enforceable rules and definitions that provide certainty and accountability.

All users of space want and need access that is not limited by problems of orbital debris. But to achieve this goal, the users of space, individually and collectively, must be prepared to make some sacrifices. The sacrifices are mostly economic: limitations on the amount of fuel a satellite can carry because essential debris mitigation measures impose a mass penalty, limitations on the mission lifetime imposed by the necessity of debris-avoidance maneuvers and relocation to disposal orbits, or the costs necessary to study and track debris. These economic costs can create tension between States, or between civil, commercial, and military users of space. Comprehensive, mandatory mitigation rules accompanied by increased accountability can help reduce the costs in the long-term by providing a safer space environment. The international community should redouble its efforts to find the best possible technical and legal solutions to this growing problem.

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