SPACE DEBRIS: LEGAL AND POLICY IMPLICATIONS

by

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DEDICATION

To Sherry for her love and support
To Tobi and Daniel for their future

May our house be safe from tigers.

ABSTRACT

The purpose of this thesis is to describe the legally relevant technical aspects of the space debris issue and to analyse the legal and policy implications derived from these facts.

Chapter One provides a detailed description of the technical aspects of the space debris issue. Topics discussed are the sources of space debris, the risks posed by space debris to space activities and to the outer space environment, the locations of space debris and its detection, and the probability of the occurrence of a space debris risk event.

Chapter Two offers a comprehensive analysis of the legal and policy implications of the space debris issue in order to evaluate the adequacy of the present international legal régime for recognizing and regulating space debris. The first section of the chapter examines the relationship between space debris and the international law of outer space; the second section examines the effectiveness of present legal mechanisms for the regulation of space refuse, the proposed legal term of art for space debris.

RESUME

Le but de cette thèse est de décrire les aspects techniques qui sont juridiquement pertinents à la question de débris dans l'espace et d'en analyser les implications juridiques et politiques.

Le premier chapitre contient une description détaillée des aspects techniques reliés à la question de débris dans l'espace. Parmi les sujets discutés l'on retrouve: les sources de débris dans l'espace, les risques posés par ces débris aux activités spatiales et à l'environnement spatial, les endroits où l'on retrouve ces débris et leurs moyens de détection, et, finalement la probabilité que les débris dans l'espace causeront un jour un évènement risqué.

Le deuxième chapitre analyse les implications juridiques et politiques du problème posé par la présence de débris dans l'espace, afin d'évaluer si le régime juridique international existant est suffisant pour reconnaître et réglementer cette question. La partie un de ce chapitre se penche sur les liens entre le problème de débris dans l'espace et le droit international de l'espace. La partie deux examine l'efficacité des mécanismes juridiques actuels pour la réglementation de "rebuts spatiaux", le terme juridique proposé pour les débris dans l'espace.

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INTRODUCTION

Today the greatest hazard facing human activities in outer space is space debris. These man-made objects orbiting Earth pose dangers to spacecraft and astronauts alike. The space debris hazard has already introduced new safety issues for consideration by national space agencies, spacecraft designers, space station manufacturers, scientists and insurance underwriters.

Space debris presents a significant hazard to current space systems, is given serious consideration as a risk to future manned spacecraft and space stations, and may eventually render certain portions of near-Earth space unusable. Moreover, space debris is virtually impossible to remove once it has been placed in outer space.

While there has been much discussion of the material problems which space debris poses, there has been little serious analysis of the legal and policy issues which this hazard raises. This thesis is the first academic effort to describe the legally relevant technical aspects of the space debris issue and to analyse the legal and policy implications derived from these facts.

A detailed description of the technical aspects of the space debris issue is provided and is specifically intended to give the legal community an understanding of the context in which the problem arises. Topics addressed are the sources of space debris, the risks posed by space debris to space activities and to the outer space environment, the locations of space debris and its detection, and the probability of the occurrence of a space debris risk event.

A comprehensive analysis of the legal and policy implications of the space debris issue is provided in order to evaluate the adequacy of the present international régime for recognizing and regulating space debris. The relationship between space debris and the international law of outer space is examined first. Commencing with a proposal for establishing "space refuse" as a legal term of art, this section analyses the concept of "space object" and the legal issues of jurisdiction and control over space refuse, international responsibility for space refuse, identification of space refuse and compensation for damage caused by space refuse. Next, the effectiveness of present legal mechanisms for the regulation of space refuse is examined through an analysis of international law and international policy and with reference to the national space law and policy of the United States and the United Kingdom.

CHAPTER ONE: TECHNICAL ASPECTS

A/ SOURCES OF SPACE DEBRIS

All man-made debris orbiting in outer space (space debris) is generated by manned and unmanned space programmes of the world's space-capable nations and international organizations. While meteoroids are a source of naturally-occurring orbital debris, they are not considered to be a serious hazard.

Space debris poses a much greater risk of harm to manned and unmanned space activities than its natural counterpart does, for several reasons. First, the meteoroid population is essentially consistent, while the quantity of space debris is steadily increasing.[1] Second, meteoroids are transient through the near-Earth environment; space debris is permanent in its orbit during its lifetime, thereby posing a risk over a greater period of time.[2] Third, since space debris is largely confined to Earth orbits, it occupies a much smaller volume

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[1] M.G. Wolfe, "Orbital Debris -- Current Issues as They Impact on an Expanding Material Presence in Space" (1985), 28 **Colloquium Law of Outer Space** 260 at 261. Readings from meteoroid sensors indicate that the microparticulate population alone may already exceed the natural meteoroid environment; D.J. Kessler and S-Y Su (eds.), **Orbital Debris. Proceedings of a Workshop sponsored by the NASA Lyndon B. Johnson Space Center, Houston, July 27-29, 1982** (Washington, DC: NASA Scientific and Technical Information Branch, 1985) 8. Subsequent re-examination of the data obtained from a sensor on board Explorer 46, which was intended to evaluate the effectiveness of double-wall structures to protect against meteoroids, revealed that most of the impacts were from microparticulate matter; see D.J. Kessler, "Impacts on Explorer 46 from an Earth Orbiting Population" in Kessler and Su, **ibid.**, 220 at 220 and, **infra**, A/4(a).

[2] American Institute of Aeronautics and Astronautics, "Space Debris" in Kessler and Su, **ibid.**, 365 at 366.

than do interplanetary natural materials.[3] Finally, as part of the universal background through which Earth passes, the presence of the meteoroid population has already been accounted for in spacecraft design.[4]

The space debris population can be divided into four classes: inactive payloads, operational debris, fragmentation debris and microparticulate matter. In 1987, there were more than 7,000 trackable objects in outer space.[5] As of December 1984, inactive payloads accounted for 20 per cent of the trackable population; operational debris, 25 per cent, and fragmentation debris, 50 per cent.[6] Microparticulate populations can only be estimated, since they are untrackable.

Excluding inactive payloads, which several commentators

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[3] D.J. Kessler, "Earth Orbital Pollution" in E.G. Hargrove (ed.), **Beyond Spaceship Earth: Environmental Ethics and the Solar System** (San Francisco: Sierra Club Books, 1986) 47 at 48-49. Consequently, the estimated total mass of space debris below 2,000 km altitude is 2,000,000 kg. For the meteoroid population, the mass is about 200 kg; Draft Special Report of the USAF Scientific Advisory Board **Ad Hoc** Committee on Current and Potential Technology to Protect Air Force Space Missions from Current and Future Debris (Washington, DC: The Pentagon, 1986) 1.

[4] D. Fielder, "Considerations for Policy on Man-Made Debris Propagation Control" in Kessler and Su, **supra**, note 1, 410 at 412.

[5] D. McKnight, "Determining the Cause of a Satellite Breakup: A Case Study of the Kosmos 1275 Breakup". Pre-print of a paper prepared for presentation at 38th Congress of the IAF, Brighton, 10-17 October 1987, at 1.

[6] E.A. Roth, "Space Debris -- A Hazard for the Space Station?" (1985), 44 **ESA Bulletin** 63 at 64. Active payloads comprise just 5 per cent of the trackable orbiting objects.

do not consider to be space debris,[7] about 57 per cent of the remaining material has been generated by the United States, 40 per cent by the Soviet Union and 3 per cent by a combination of the United Kingdom, the European Space Agency (ESA), France, West Germany, India, Japan and the People's Republic of China.[8]

The length of time an item of space debris will remain in outer space is related to its orbital period, ie, the time it takes a space object to complete one circuit around Earth. If the orbital period is less than 95 minutes, natural decay mechanisms will cause the fragments to decay in a relatively short period of time. With lengthier periods, space debris can cause an "essentially permanent threat" to space navigation.[9]

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[7] See, eg, E. Marshall, "Space Junk Grows with Weapons Test" (1985), 230 Science 424 at 424, R.C. Hall, "Comments on Traffic Control of Space Vehicles" (1965), J Air L & Comm 327 at 328 and D.J. Kessler and B.G. Cour-Palais, "Collision Frequency of Artificial Satellites: Creation of a Debris Belt" in H.B. Garret and C.P. Pike (eds.), Space Systems and Their Interactions with Earth's Space Environment (NY: American Institute of Aeronautics and Astronautics, 1980) 707 at 707; originally published in (1978), J Geophysical Research 2637. The latter also excludes jettisoned rocket motors from the operational debris category.

[8] Marshall, id.

[9] Wolfe, supra, note 1 at 261 and 263. For a discussion of natural decay mechanisms, see, infra, text accompanying notes 219-223.

1. INACTIVE PAYLOADS

Inactive payloads are those former active payloads which can no longer be controlled by their operators.[10] More than 1,000 inactive payloads are now orbiting Earth at altitudes from a few hundred kilometres to 100,000 km and with orbital lifetimes of many hundreds of years or more.[11] Spent Earth-orbiting satellites and space probes dominate this category.[12]

2. OPERATIONAL DEBRIS

Operational debris are those objects associated with space activities, which remain in outer space. Since Sputnik I was launched more than 30 years ago, some 7,500 of these mission-related objects have been deposited in outer space.[13] Mostly launch hardware, operational debris also includes items placed in outer space, either accidentally or deliberately, by humans during manned missions. If the object is intentionally left by an astronaut or cosmonaut, then it is litter.

The largest pieces of operational debris are associated with placing satellites in orbit. They consist of burnt-out

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[10] Loss of control over a functioning space object may occur due to the depletion of station-keeping fuel or the inability to communicate with the object; W.B. Wirin, "The Sky is Falling[:] Managing Space Objects" (1984), 27 Colloquium Law of Outer Space 147 at 151.

[11] N.L. Johnson, "Preventing Collisions in Orbit" (May-June 1987), SPACE 1 at 17.

[12] Wirin, supra, note 10 at 151.

[13] Johnson, supra, note 11 at 17. Many of these space objects have re-entered the Earth's atmosphere and disintegrated.

first and second stage rocket bodies, orbital transfer vehicles (OTVs) and apogee kick motors.[14] Other mission-related objects include nose cones[15] and payload separation hardware (eg, ejected satellite shrouds and clamps,[16] exploded restraining bolts,[17] fairings[18] and unattached release straps[19]), de-spin weights and staging mechanisms,[20] exploded fuels tanks and insulation,[21] window and lens covers[22] and a camera from an Apollo mission[23]. Technical mishaps have contributed raw propellant inadvertently dumped during fuel

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[14] OTVs carry payloads from a low-Earth orbit (LEO) to the geostationary orbit (GEO); apogee kick motors circularize the trajectory of the payload at the geostationary altitude.

[15] D.J. Frederick, "Litter in Space Increasing: Orbiting Trash Can Proposed" (March 1985), Space World 17 at 18.

[16] Marshall, supra, note 7 at 424.

[17] D.A. Olmstead, "Orbital Debris Management: International Cooperation for a Growing Safety Hazard" in G.W. Heath (ed.), Space Safety and Rescue 1982-83. Proceedings of the 15th and 16th International Symposia on Space Safety and Rescue held in conjunction with the 33rd and 34th International Astronautical Congresses (San Diego, CA: Univelt, 1984) 241 at 243.

[18] "Debris -- The Pollutant of Outer Space" (unpublished paper, Webster University, CO, February 1987) 3.

[19] R. DeMeis, "Cleaning Up Our Space Act" (February-March 1987), Aerospace America 10 at 10.

[20] Id.

[21] Marshall, supra, note 7 at 424.

[22] M.S. Smith, "Program Details of Man-Related Space Flights" in Staff of Senate Comm. on Aeronautical and Space Sciences, Report on Soviet Space Programs, 1971-75: Volume I (Comm. Print 1976) 173 at 195 and Johnson, supra, note 11 at 17.

[23] Wirin, supra, note 10 at 16.

transfers[24] and "transient bits of frozen sewage" from the space shuttle[25].

Human spacefarers have also left their mark in the form of an astronaut's glove,[26] screws lost during the Solar Maximum satellite repair mission[27] and other "odds and ends" left by astronauts. Littering is not the exclusive domain of either major space power. US Gemini astronauts Young and Collins threw a trash bag overboard "in a manner reminiscent of earth bound motor car travellers";[28] Soviet cosmonauts have jettisoned from the Salyut 7 space station medicine ball-sized bags of garbage containing "dirty clothes, food wrappers, and other trash".[29]

In addition to mission-related debris in orbit, items from space exploration activities remain on celestial bodies. Various paraphernalia resulting from the Apollo missions are still on the Moon; failed space probes, such as the Viking 1

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24 B. Nolley, "Last Gas for 22,000 Miles" (February 1987), Space World 26 at 27. Leaked fuel freezes into flaky crystals.

25 Marshall, supra, note 7 at 424.

26 "Debris -- The Pollutant of Outer Space" (unpublished paper, Webster University, CO, February 1987) 3.

27 DeMeis, supra, note 19 at 10.

28 R.C. Hall, "Comments on Salvage and Removal of Man-Made Objects from Outer Space" (1966), 9 Colloquium Law of Outer Space 117 at 117.

29 J.E. Oberg, "Eyes on the Sky" (May 1987), Air and Space 42 at 42-43. These objects remain in orbit for several weeks before they disintegrate; ibid., at 43.

on Mars,[30] remain on the surface of other planets in our solar system.

3. FRAGMENTATION DEBRIS

Fragmentation debris is produced when space objects break up as a result of explosions, collisions and possibly other unknown phenomena. Fragmentation debris from nearly 100 identified satellite breakups accounts for 46 per cent of all catalogued space objects in Earth orbit, and is found at altitudes below 2,000 km where many applications satellites function and where all manned operations take place.[31]

(a) Explosions

Explosions may be deliberate or accidental. As of 7 February 1987, approximately 90 catalogued explosions[32] have contributed more than 36,000 kg of debris fragments to the outer space environment, with a significant portion of this mass in the untrackable range of 1 mm to 1 cm.[33] Deliberate explosions result mainly from military programmes; accidental

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30 "Satellites in Trouble" (August-September 1983), Space World 20 at 21. Viking 1 failed in May 1976.

31 Johnson, supra, note 11 at 17.

32 D.M. Nelson, "Space Debris[:] The Peril in Orbit" (unpublished paper, Webster University, CO, February 1987) 2.

33 "Debris -- The Pollutant of Outer Space" (unpublished paper, Webster University, CO, February 1987) 3-4.

explosions are generally related to propulsion system failures.[34]

(i) Deliberate

Deliberate explosions are detonated to prevent recovery of certain satellites and to test military weapons.

The Soviet Union has intentionally exploded certain photographic reconnaissance satellites as a means of preventing their recovery by unfriendly nations, when a formal re-entry was impossible.[35] In addition, the weight of circumstantial evidence favours deliberate explosions as the cause of the fragmentation of at least eight conventionally-powered Soviet ocean surveillance satellites.[36]

Three examples of deliberate destruction are Kosmos 1654, exploded on 21 June 1985 to prevent recovery;[37] Kosmos 1813, a USSR military surveillance satellite, exploded on 29 January 1987 to prevent either recovery by the United States or impact on a populated area after an uncontrolled re-entry,[38] and

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[34] Johnson, supra, note 11 at 17.

[35] N.L. Johnson, "Artificial Satellite Breakups (Part 1): Soviet Ocean Surveillance Satellites" (1983), 36 J Brit Interplanetary Soc 51 at 51.

[36] Ibid., at 58. The reason for these intentional explosions is unknown. However, accidental detonation due to a defective propulsion unit has not been ruled out; ibid., at 57.

[37] Roth, supra, note 6 at 64.

[38] "Soviet Proton Booster Fails; Reconnaissance Satellite Explodes", AvWk&SpTech (9 February 1987) 26-27. The explosion produced more than 100 trackable pieces of fragmentation

Kosmos 1906, a new commercial imaging satellite, exploded on 31 January 1988 to prevent possible recovery by the United States[39].

The anti-satellite (ASAT) programmes of the United States and the Soviet Union and the US Strategic Defence Initiative (SDI) are also responsible for deliberate explosions.

The term "ASAT" is used to describe any device capable of destroying the operational capability of satellites in Earth orbit. These devices may be ground-based, air-based or space-based.[40] The two major components of an ASAT system are the interceptor and the target. During testing, only the interceptor breaks up; there is no evidence to suggest that target fragmentation occurs.[41] Every explosion is capable of producing up to 10 million particles[42] which are concentrated

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debris in orbits more than 160 km higher than the spacecraft's 380-km orbit at the time of destruction. At those heights, it is unlikely any of the debris remained in orbit, due to the effects of atmospheric drag.

39 "Soviet Imaging Satellite Explodes; Proton Booster Launch Fails", **AvWk&SpTech** (22 February 1988) 23. The explosion placed more than 100 pieces of space debris in orbit.

40 M.I. Stojak, **Legally Permissible Scope of Current Military Activities in Space and Prospects for Their Future Control** (Montreal: McGill University, 1985) 32-33.

41 N.L. Johnson, "Artificial Satellite Breakups (Part 2): Soviet Anti-Satellite Program" (1983), 36 **J Brit Interplanetary Soc** 357 at 358-61. Although two target satellites have disintegrated in orbit, this phenomenon occurred long after they fulfilled their ASAT mission; see, **infra**, text accompanying note 73.

42 F.K. Schwetje, "Space Law[:] The Legal Aspects of Space Debris Control and Space Salvage Operations". Paper prepared for presentation at the Inter-American Bar Associa-

at approximately 800 km altitude[43]. If the target of an ASAT attack were a satellite with a nuclear power source (NPS) on board, the explosion could release radioactivity as well as fragments.[44]

The Soviet Union has an operational ground-based ASAT system which it has been testing since 1968. The interceptor satellites are launched into an orbit close to that of the target satellite and explode about 1 km from their targets.[45] If the test is unsuccessful and the interceptor remains intact, it may still be exploded.[46]

The Soviet ASAT programme can be divided into two phases. From 1968 to 1971, seven ASAT tests resulted in the breakup of six Soviet interceptors which, as of 1 February 1983, had accounted for 438 pieces of trackable debris.[47] The second phase began in 1976. Of the 10 tests flown until April 1983, three interceptor fragmentations created 136 trackable pieces of space debris.[48] Although four other interceptors frag-

tion meeting, Buenos Aires, May 1987, at 4.

43 M.S. Smith, "Protecting the Earth and Outer Space Environment: Problems of On-Orbit Space Debris" (1982), 25 Colloquium Law of Outer Space 45 at 46.

44 Id.

45 Stojak, supra, note 40 at 33.

46 "New Soviet Antisatellite Mission Boosts Backing for US Tests", AvWk&SpTech (28 April 1980) 20.

47 Johnson, supra, note 41 at 358.

48 Ibid., at 358 and 360.

mented, a reduction in the flight time by half enabled any debris to decay in the Earth's atmosphere.[49]

The US ASAT programme can also be divided into two phases. Phase I ran from 1964 until 1975, using nuclear warheads launched by ground-based missiles. Phase II began in 1982 as a response to the continued Soviet effort, and consists of a miniature homing vehicle (MHV) which would be launched from a two-stage rocket, carried by an F-15 aircraft.[50] The US Air Force (USAF) is also examining the possibility of complementing the MHV system with free-electron lasers in the future.[51] Unlike their Soviet counterparts, US ASATs will destroy their targets by impact,[52] possibly producing less debris[53]. The system began testing in Autumn

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[49] Ibid., at 360.

[50] Stojak, supra, note 40 at 39-41.

[51] "Defense Dept. Unveils $1.2-Billion ASAT Restructuring Plan", **AvWk&SpTech** (16 March 1987) 19 at 20. See also, "Physicists Assess Laser Lethality for Ballistic Missile Defense Role", **AvWk&SpTech** (18 May 1987) 104.

[52] Stojak, supra, note 40 at 39-41.

[53] Smith, supra, note 43 at 46. Notwithstanding this possible reduction, US ASAT tests are adding to the debris population. Eg, on 13 September 1985, a US missile struck an old Air Force satellite (P78-1) in a low polar orbit of about 530 km altitude, creating "100s of bits of debris"; Marshall, supra, note 7 at 424.

1985[54] and is expected to become operational in the early 1990s[55].

The SDI programme, announced in March 1983, will provide the US with a space-based capability to intercept and destroy strategic ballistic missiles systems before they can reach the ground.[56] Opinion is divided on whether SDI weapons tests will substantially increase the space debris population. One analyst has stated that these tests "could present a major debris problem".[57] Another has suggested that the tests would not necessarily add to the problem if they are conducted below 570 km, thereby enabling the debris to decay within a few weeks following the test.[58]

(ii) Accidental

Accidental fragmentation is generally the result of a propulsion system failure, although engine failures during operations have also resulted in satellite explosions.[59] Old

54 "Reagan Orders Test of Antisatellite Vehicle Against Space Target", **AvWk&SpTech** (26 August 1985) 23. The two initial ASAT launches in 1984 did not involve intercepting an object in space; ibid, at 24.

55 "Defense Dept. Unveils $1.2-Billion ASAT Restructuring Plan", **AvWk&SpTech** (16 March 1987) 19.

56 Stojak, supra, note 40 at 43.

57 Smith, supra, note 43 at 46.

58 DeMeis, supra, note 19 at 11.

59 Johnson, supra, note 11 at 17. Eg, the explosion of Kosmos 1423 in December 1982 was due to engine failure.

US and USSR rocket bodies whose fuel tanks have exploded are a prime source of debris.[60]

Perhaps the classic example of propulsion system failure is that of the second stages of the US Delta rockets. Beginning in 1973, seven Delta second stages exploded after successfully performing their payload delivery missions, producing 1,230 known space debris objects.[61] More importantly, some of these rockets were presumed dead in outer space for as long as three years prior to exploding.[62] Subsequent investigation revealed that residual hypergolic (self-igniting) propellants were responsible for the explosions.[63] As a result of this discovery, depletion burns were implemented in the early 1980s following payload deployment. With the tanks emptied, no further explosions of this type occurred.[64] As of June 1981, more than 22 per cent of the total space debris population was attributable to these Delta explosions.[65]

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[60] Frederick, supra, note 15 at 17.

[61] Johnson, supra, note 11 at 17-18.

[62] Schwetje, supra, note 42 at 4.

[63] DeMeis, supra, note 19 at 11. Shutting the propellant tank vent valves had allowed pressure to build up, until one of the two fuel tanks in the rocket ruptured and shot fragments into the other. The hypergolic propellants then met and exploded; id.

[64] Johnson, supra, note 11 at 18.

[65] Johnson, supra, note 35 at 58.

The 13 November 1986 explosion of an Ariane-1 third stage booster rocket, is an event likely to be recognized as the worst satellite breakup in history.[66] Launched in February 1986, the booster exploded at an altitude of about 780 km, creating some 200 pieces of trackable space debris in orbits of about 430 to 1,340 km altitude, a region where much of the Delta debris is located.[67] As of February 1987, investigators had not settled on a definitive explanation for the accident.[68]

(iii) Cause Unknown

The cause of several recorded explosions has yet to be determined. Alternative explanations include deliberate destruction, malfunction of a satellite sub-system and collision. Examples of such debris fragmentations include the suspected breakup of two Soviet space stations[69] and the unexplained disintegration of two Soviet ASAT target satellites[70].

On 14 April 1973, 11 days after take-off, the USSR Salyut 2 space station underwent a catastrophic malfunction, leaving

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66 Johnson, supra, note 11 at 18.

67 "Used Ariane Stage Explodes, Creating Space Debris Hazard", AvWk&SpTech (1 December 1986) 34.

68 DeMeis, supra, note 19 at 11. See also, infra, text accompanying notes 131-133.

69 Smith, supra, note 43 at 46.

70 Johnson, supra, note 41 at 361.

the vehicle tumbling in space without telemetry return. An explosion or a mis-firing thruster were both suggested as causes for the incident. The most widely held theory is that the spacecraft's orbiting D-1 booster upper stage exploded, with its debris damaging the space station.[71] The decay of Kosmos 557, believed to be a manned Salyut spacecraft, has also been attributed to an explosion, although details of its demise are sketchy.[72]

The ASAT target satellites, Kosmos 839 and Kosmos 880, broke up on 29 September 1977 and 27 November 1978, respectively, long after fulfilling their missions. They are the only two target satellites known to have exploded. Although it is impossible to ascertain what caused these explosions,the most likely explanation is a collision with debris.[73]

(b) Collisions

Fragmentation debris caused by collisions poses a greater threat to active payloads than breakup fragments from explosions. Collision-induced fragmentation debris is produced in greater quantities than explosion fragments, is generally too small to be tracked and travels at speeds far greater than its explosion-induced counterpart.[74]

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[71] Smith, supra, note 22 at 194-95.

[72] Ibid., at 195-96.

[73] Johnson, supra, note 41 at 361-62.

[74] Johnson, supra, note 11 at 18. See also, infra, B/1.

(c) Cause Unknown

Certain incidents of debris fragmentation cannot be attributed to a specific cause. Examples include the breakups of Transit 4A, Kosmos 954, SNAP-10A and Kosmos 1275.

The first known satellite breakup was the Transit 4A Ablestar rocket body on 29 June 1961. With 206 pieces still in orbit, this incident ranked in 1986 as the third worst fragmentation event on record. Although the exact cause of the accident is not known conclusively, an inadvertent activation of the range safety destruct package is considered the likely culprit.[75]

Kosmos 954 is perhaps the most infamous case of fragmentation to date. Launched on 18 September 1978, the Soviet ocean surveillance satellite became uncontrollable, prematurely re-entered the atmosphere, deposited radioactive debris over Northern Canada and was responsible for an expensive cleanup of the contaminated region. The cause of the fragmentation is not yet confirmed. A Soviet spokesman stated that the satellite collided in flight with either a meteorite or space debris;[76] Canadian officials stated that the separation was caused by an engine malfunction.[77] The latter explanation is more convincing, since those monitoring the Kosmos 954 were

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[75] Johnson, ibid., at 17.

[76] "Fallen Nuclear Satellite Poses No Danger" (1978), 30 Current Digest Soviet Press (1 March) 1.

[77] "Intensive Analysis Under Way on Cosmos Debris in Canada", AvWk&SpTech (13 February 1978) 22-23.

aware of its irregular behaviour before its failure on 6 January 1978.[78]

SNAP-10A, the only US nuclear reactor spacecraft placed in orbit by September 1986, was launched in April 1965 in a 1,300 km orbit. Since late 1979, SNAP-10A has produced pieces of space debris on at least six occasions. The nature of the debris and the cause of its liberation are unknown.[79]

Kosmos 1275 broke up into more than 200 trackable fragments on 24 July 1981 at an altitude of 977 km. Although there is still much uncertainty due to a lack of information about the fragmentation, it has been speculated that the event was the result of a hypervelocity collision with space debris.[80] Evidence in support of this theory is becoming increasingly difficult to refute.[81]

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[78] **Id.**

[79] "Radioactive Space Debris Study Cites Hazards to Satellites, Earth", **AvWk&SpTech** (22 September 1986) 19 at 20. SNAP stands for Systems for Nuclear Auxiliary Power. All odd-numbered SNAP power plants use radioisotope fuel. Even-numbered units have nuclear fission reactors as a source of heat; Wirin, **supra**, note 10 at 154. See also, text accompanying note 144.

[80] Hypervelocity speeds occur when an object travels at 1 km/sec or more.

[81] McKnight, **supra**, note 5 at 1 and 7. See also, **infra**, text accompanying notes 126-127.

4. MICROPARTICULATE MATTER

Varying in size from 1-100 microns,[82] microparticulate matter consists of particles, gases and spaceglow. It has been estimated that between 10 billion and thousands of trillions of microparticulates are present in outer space.[83] This class of space debris is created from various sources, including solid-propellant rocket motors, surfaces of orbiting objects and manned spacecraft.

(a) Solid-propellant Rocket Motors (SRMs)

SRM effluent comes from three sources: the exhaust plume during rocket firing, the rocket nozzle during the postfire period and SRM auxiliary hardware.

Effluent sampling of inertial upper stage (IUS) exhaust plumes has revealed production of aluminum oxide particles ranging from 0.25-5.5 microns,[84] solid carbon particles of

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82 D.J. Kessler, "Space Debris: More Than Meets the Eye" (June 1987), **Sky & Telescope** 587 at 587. One micron is one millionth of a metre.

83 M.G. Wolfe and L.P. Temple III, "Department of Defence Policy and the Development of A Global Policy for the Control of Space Debris". Pre-print of a paper prepared for presentation at 38th Congress of the International Astronautics Federation, Brighton, 10-17 October 1987, at 3.

84 In composite SRMs, metallic aluminum is often mixed with the solid propellants to make them burn faster. As a result, the final product of combustion is aluminum oxide in the form of solid particulates; see F. Zwicky, "Examples of Activities in Extraterrestrial Space Which Might be Judged Harmful, Harmless, Useful, or Either[sic] One of These, Depending on the Viewpoint" (1972), 15 **Colloquium Law of Outer Space** 259 at 261 and P.T. Girata Jr. and W.K. McGregor, "Particle Sampling of Solid Rocket Motor Exhausts in High Altitude Test Cells" in J.A. Roux and T.D. McCay (eds.),

submicron size[85] and particles of potassium, phosphorus, chlorine, sodium and calcium in a molten state[86]. Gases emitted during the rocket burn include principally carbon dioxide and nitrogen, with smaller amounts of oxygen and various hydrocarbons.[87]

During the postfire period, effluent may be emitted from the nozzle, possibly for as long as 20-35 minutes. All effluent constituents have not yet been identified; however, it is known that gaseous and particulate substances are given off when the propellant has burned out.[88] During this phase, the major contaminants are oil and grease, both of which are released when the nozzle flexible-seal components rupture.[89]

Spacecraft Contamination: Sources and Prevention (NY: American Institute of Aeronautics and Astronautics, 1984) 293 at 293. It has been estimated that more than 450 kg of aluminum oxide particles have been deposited in outer space. In contrast, there are about 200 kg of meteoric material below 2,000 km; SAB draft report, supra, note 3 at 1. It is estimated that tens of hundreds of trillions of aluminum oxide particles, generally smaller than 0.01 mm (10 microns) in diameter, are in outer space; Kessler, supra, note 82 at 587 and Wolfe and Temple, supra, note 83 at 3.

85 During the combustion process, carbon microparticulates result from erosion of the carbon-carbon rocket exhaust nozzles; Girata and McGregor, ibid., at 294.

86 P.T. Girata and W.K. McGregor, "Postfire Sampling of Solid Rocket Motors for Contamination Sources in High-Altitude Test Cells" in Roux and McCay, supra, note 84, 312 at 325.

87 Id.

88 Ibid., at 313.

89 Ibid., at 326.

Outgassing of adjacent materials outside the nozzle produces unknown contaminants which result when heat from the SRM nozzle is transferred to the surrounding surfaces. Also, more importantly, emissions from auxillary hardware (eg, actuators and lubricated seals) may occur for several minutes after burnout, due to thermal heating.[90]

(b) Surfaces of Orbiting Objects

Various coatings and materials used in spacecraft, notably paints and their binder agents, leave bits of space debris behind. This coating degradation and chipping is due to exposure to ultraviolet radiation and atomic oxygen and to expansion and contraction stresses resulting from severe changes in temperature.[91]

(c) Manned Spacecraft-induced Objects

The first four flights of the space transportation system (STS) orbiter revealed a variety of STS-induced microparticulate matter, both planned and unplanned. Released materials included cabin leakage, outgassing of heavy molecules, water dumps, flash evaporator system operation, reaction control system engine firings and particle and gas releases. Future orbiter payloads will be protected from this type of space debris through the use of protective coverings. Other

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[90] Ibid., at 313-14.

[91] Frederick, supra, note 15 at 17-18. It has been estimated that there are trillions of paint flakes in outer space; Wolfe and Temple, supra, note 83 at 3.

occasional events such as the operation of engines and payload bay doors are causes for "excessive molecular and/or particulate contamination...".[92]

The orbiter also exhibited a radiated glow (spaceglow) which extended outward from its surfaces.[93] Although it is a transient phenomenon, spaceglow is a potential debris source since it interferes with space-based optical measurements.[94] Spaceglow is not yet well understood by scientists. What is known is that a continuous glow exists during passive operation conditions and thruster firings.[95] Recent studies indicate that spaceglow depends on the energy transfer to and the subsequent desorption of adsorbed species such as nitrogen compounds, particularly nitrogen dioxide.[96]

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[92] H.K.F. Ehlers et al., "Space Shuttle Contamination Measurements from Flights STS-1 Through STS-4" (1984), 21 J Spacecraft & Rockets 306 at 306 and 307. In these studies, the cargo bay of the orbiter was virtually empty. Therefore, the amount of space debris created when payloads are on board may be significantly greater.

[93] R.K. Cole et al., "Atomic Oxygen Simulation and Analysis" (1987), 15 Acta Astronautica 887 at 887.

[94] Ibid., at 889.

[95] B.D. Green et al., "The Shuttle Environment: Gases, Particulates and Glow" (1985), 22 J Spacecraft & Rockets 504 at 504, 506 and 510.

[96] Cole, supra, note 93 at 890-91.

B/ RISKS POSED BY SPACE DEBRIS

Collision and interference are the major risks space debris poses to human life and active payloads. A collision may result in loss of property or life, damage to persons or property, generation of further debris, misinterpretation, release of contamination, or the need to alter space operations or space object design. Interference with scientific, commercial and military space activities may be caused by the quantity of debris accumulating in outer space. The possibility also exists that space debris could be used for military purposes.

The threat from space debris varies with the size of debris objects encountered. As Table 1 on the next page illustrates, possible harms range from loss of the capabilities of a satellite sub-system to spacecraft obliteration.[97] Objects of the greatest concern are between 0.1 and 10 mm in diameter.[98] Present spacecraft systems are particularly vulnerable, mainly because they have not been designed with these threats in mind.[99]

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97 D.S. Edgecombe et al., "Space Craft Design Alternatives to Accommodate the Collision Threat Posed by Orbiting Man-Made Debris" in Heath, supra, note 17, 223 at 226.

98 SAB draft report, supra, note 3 at 4.

99 Edgecombe, supra, note 97 at 226.

TABLE 1 - RISK OF DEBRIS SUMMARY[100]

DEBRIS SIZE (MASS)	NATURE OF THREAT	RELATIVE PROBABILITY
SUBMILLIMETRE (microgram)	DEGRADE OPTICS, SOLAR PANELS	MOST PROBABLE
MILLIMETRE (milligram)	PENETRATE UNSHIELDED SATELLITE OR SPACECRAFT	LESS PROBABLE THAN ABOVE
CENTIMETRE (gram)	PENETRATE SHIELDED SATELLITE OR SPACECRAFT	LESS PROBABLE THAN ABOVE
DECIMETRE (kilogram)	FRAGMENT SATELLITE OR SPACECRAFT	LEAST PROBABLE

1. COLLISION

(a) Loss of or Damage to Persons and Property

(i) Loss

A common assumption about space debris is that the collision hazard it poses is not a serious one. Over time this is not the case. With speeds averaging 10 km/sec (more than 35,000 km/hour), a 0.5-mm chip of paint could puncture a standard space suit, killing an astronaut engaged in extravehicular activity (EVA).[101] The risk of such a

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100 Adapted from Table 1, id.

101 L.P. Temple III, "The Impact of Space Debris on Manned Space Operations". Paper prepared for presentation at the AIAA Space Systems Technology Conference, San Diego, CA, 9-12 June 1986, at 6 and Wolfe and Temple, supra, note 83 at 3.

collision has increased four orders of magnitude in ten years.[102]

At these speeds, a collision between a piece of space debris and a spacecraft could be catastrophic.[103] For example, if a debris object one centimetre in diameter struck a space station, it could penetrate the pressurized crew module, killing the crew and causing the station to break up.[104] The same object could pierce the window of a space shuttle, killing its occupants and seriously damaging the spacecraft,[105] or could disable or destroy a satellite in GEO, since the collision would eject from the satellite a mass of 115 times the mass of the impacting debris[106].

(ii) Damage

Collisions with space debris could cause varying degrees of damage. "Graceful" degradation of spacecraft capability could occur, due to pitting or fracturing of optical surfaces,

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102 Temple, **ibid.**, at 6. One order of magnitude is a factor of 10.

103 M. Nagatomo, "Earth Satellite Collision Probability in Space Station Era" (1986), 13 **Acta Astronautica** 333 at 333.

104 "Station Likely To Be Hit By Debris", **AvWk&SpTech** (17 September 1984) 16 and Edgecombe, **supra**, note 97 at 226.

105 A. Oberg, "Trashing the Orbital Frontier" (October 1984), **Science Digest** 41 at 42-43.

106 S. Wiessner, "The Public Order of the Geostationary Orbit: Blueprints for the Future" (1983), 9 **Yale J World Publ Order** 217 at 226-27. For a summary of this article, see "Access to a **Res Publica Internationalis**: The Case of the Geostationary Orbit" (1986), 29 **Colloquium Law of Outer Space** 147.

solar cell cover glasses or special thermal coatings; the skin of a spacecraft (shielded or unshielded) could be penetrated, leading to damage or destruction of secondary sub-systems (eg, computers and communications equipment) or of even more robust sub-systems (eg, propulsion system components and high-pressure fuel tanks).[107] In addition, launching upper stages with SRMs in the vicinity of the STS orbiter leaves open the possibility of damage to thermal protection tiles and crew observation windows from the impact of single large particles or from erosion caused by a high velocity cloud of small particles.[108]

The risk of damage is not limited to manned spacecraft and satellites, but also includes a significant and escalating danger to Earth-orbiting observatories such as the Hubble Space Telescope.[109]

(iii) The Evidence

The first indication that space debris was colliding with active payloads was obtained from Explorer 46. Launched on 13 August 1972, this satellite included a meteoroid bumper

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[107] Edgecombe, supra, note 97 at 226.

[108] Girata and McGregor, supra, note 84 at 294.

[109] "Hubble Trouble?" (January 1987), Sky & Telescope 31. The Hubble telescope is the first in a series of Great Observatories planned by the US space science programme for placement in LEO; W.W. Mendell and D.J. Kessler, "Limits to Growth in Low Earth Orbit". Paper IAA-87-574, prepared for presentation at 38th Congress of the IAF, Brighton, 10-17 October 1987, at 1-2. See also, infra, note 167.

experiment which was sensitive to impacts by particles larger than about 0.1 mm. Analytical results of the 43 impacts with Explorer 46 can only be explained by a population of Earth-orbiting objects. The orbital flux was 1.9, about a factor of 3 below that for meteoroid flux.[110]

The first real proof that space debris was striking active payloads was the Skylab cosmic dust experiment, S-149. Its purpose was to look for meteoroid impacts. Chemical analysis revealed a high incidence of aluminum in the impact craters,[111] the source of which could only be man-made.

Windows on the returned Skylab IV Apollo Command Module were also examined for meteoroid impacts. It was discovered that about 50 per cent of the hypervelocity pits covering the windows were aluminum lined, probably the result of collisions with aluminum oxide particles from SRM exhaust.[112]

The windshield of the STS orbiter Columbia suffered damage during the STS-5 mission and had to be replaced after it was likely struck by a 13x13 cm metal tile carrier plate dislodged from the orbiter's nose on re-entry.[113] Although

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110 Kessler, supra, note 3 at 57-58 and SAB draft report, supra, note 3 at 2. The orbital flux factor represents the number of objects found in one square metre every year.

111 Wolfe and Temple, supra, note 83 at 3-4 and Kessler, ibid., at 57.

112 Kessler, ibid., at 57; Frederick, supra, note 15 at 18, and Wolfe and Temple, ibid., 63 at 4.

113 "Strike Craters Shuttle Windshield, Forces Replacement", AvWk&SpTech (11 July 1983) 18.

not strictly a collision with debris separate from the spacecraft, it could be argued that the tile is operational debris.[114]

Perhaps the most widely discussed collision to date is the Challenger windshield incident which occurred in June 1983 on the third day of the STS-7 mission. This impact represents the first confirmed damage to an operational spacecraft by space debris.[115] At first believed to be a micrometeorite impact, it was later determined that the object which damaged the orbiter's windshield was a particle of thermal paint about 0.2 mm in diameter, striking the glass at a speed of between 3-6 km/sec. The collision left a crater 2.0-2.4 mm across and 0.63 mm deep, and damaged the glass out to a diameter of 4 mm. Due to the severity of the impact, the window could not be reused.[116]

Another collision which occurred in June 1983 has gone virtually unnoticed. Shortly after payload separation, the Amsat Oscar 10 amateur radio satellite was struck twice by the Ariane third-stage rocket which launched it. The venting of residual propellant from the stage apparently pushed the

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114 This incident raises the issues of when a space object becomes space debris and whether appropriate precautions are taken on the ground to prevent the accumulation of such debris.

115 Kessler, supra, note 82 at 587.

116 "Strike Craters Shuttle Windshield, Forces Replacement", **AvWk&SpTech** (11 July 1983) 18; Frederick, **supra**, note 15 at 18; DeMeis, **supra**, note 19 at 10; Kessler, **supra**, note 82 at 587, and Kessler, **supra**, note 3 at 57.

rocket into Oscar 10. The satellite suffered damage to one of its antennae, but was able to carry out its mission.[117]

Most recently, examination of insulation blankets recovered from the Solar Maximum Mission satellite (Solar Max) has revealed hypervelocity impacts with meteoritic materials, paint particles and particles of an unknown origin.[118] Scientists found many more impacts in the blankets than expected.[119] Analysis indicates that possibly 70 per cent of these impacts resulted from space debris. The source of the particles of unknown origin remains enigmatic. It seems likely they are part of the space debris population, although it is conceivable, but highly improbable, that certain of these particles have an extraterrestrial origin.[120]

In several cases where the cause of loss of or damage to active payloads is unknown, collision has been put forward as a possible explanation. In these instances, analysts have concluded that, but for a collision, the incident would not

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117 "European Radio Satellite Hit After Ariane Separation", AvWk&SpTech (25 July 1983) 25. This incident points to the necessity of more adequate ground planning in order to avoid collisions in space.

118 Kessler, supra, note 3 at 58. Launched in 1980, Solar Max had been exposed to the outer space environment for four years and 55 days before its orbit decayed and the satellite was retrieved by the STS 41-C crew in April 1984.

119 Wolfe and Temple, supra, note 83 at 4.

120 F.J.M. Rietmeijer et al., "An Inadvertent Capture Cell for Orbital Debris and Micrometeorites: The Main Electronics Box Thermal Blanket of the Solar Maximum Satellite" (1986), 6 Advances in Space Res 145 at 147-48.

have occurred; however, even the strongest evidence is only circumstantial.

Circumstantial evidence suggests a good possibility that the US communications reflector balloon PAGEOS was fragmented in 1975 by a collision with space debris. If an object had pierced the balloon, there should have been two separate sets of fragments --one moving out from the entry hole and one from the exit hole. Computer analysis pointed to this possibility; a potential suspect for the impacting object was even identified. However, that piece was never detected again.[121]

Soviet target satellites Kosmos 839 and Kosmos 880 dissociated explosively in September 1977 and November 1978, respectively. Although it has been impossible to ascertain whether either of these satellites was struck by space debris, a circumstantial case can be made that they were struck by fragmentation debris from the Soviet ASAT Kosmos 886.[122]

Circumstances surrounding the sudden depressurization and descent to Earth of Soviet ocean surveillance satellite Kosmos 954 on 6 January 1978 suggest that a collision may have occurred.[123] The official Soviet view is that the rapid depressurization could not have been caused by other than a

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[121] J. Schefter, "The Growing Peril of Space Debris" (July 1982), Popular Science 48 at 51 and N.L. Johnson et al., History of On-Orbit Satellite Fragmentation (2d ed.). Prepared for US Army Strategic Defense Command (Colorado Springs, CO: Teledyne Brown Engineering, 1986) 1-47.

[122] Johnson, supra, note 41 at 361-62.

[123] Marshall, supra, note 7 at 425.

collision with space debris. On the other hand, US observers state that the satellite was misbehaving as early as 17 December 1977. The two versions might not be incompatible. If the satellite was out of control on 17 December, it could have subsequently collided with space debris. However, the Soviet Union denies that the satellite became inoperative before 6 January.[124]

ESA's magnetospheric satellite (Geos-2) appears to have been involved in a collision in 1978, based on the fact that this satellite was carefully designed to eliminate the damage which occurred. If this incident was the result of a collision, it is significant, since Geos-2 was stationed in GEO.[125]

The violent breakup of Kosmos 1275 (1981-53A) over Alaska in July 1981 only seven weeks after launch suggests that a hypervelocity collision might have occurred. It may be significant that this payload was at an altitude (900-1,000 km) and inclination with a relatively high probability of collision. This orbit contains debris from several fragment-

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[124] V. Rich, "The Facts About Kosmos-954" (1978), 271 Nature 497 at 498.

[125] G. Wrenn, "Geos 2 in Space Collision?" (1978), 274 Nature 631 at 631.

intensive on-orbit breakups.[126] However, the official cause of the breakup is listed as unknown.[127]

On 27 July 1983, about three weeks after the Challenger windshield incident, a window on the Soviet Salyut 7 space station was struck by a space object. The impact, heard by the two-man cosmonaut crew, formed a crater of about 3 mm in diameter.[128] Although scientists were not certain whether the damage was caused by a micrometeorite or space debris at the time, the most recent version of the incident states that the object was a micrometeorite.[129]

One case of damage possibly the result of a collision involved a Tracking and Data Relay Satellite (TDRS-A) in April 1983. TDRS-A suffered vehicle dynamics and thruster problems when it collided with its IUS booster, after the booster malfunctioned. It has been suggested that when TDRS-A separated from the booster, the spin rate of the TDRS-A

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126 N.L. Johnson, "History and Consequence of On-Orbit Break-Ups" (1985), 5 Advances in Space Res 11 at 14; Marshall, supra, note 7 at 425, and Kessler, supra, note 3 at 51-52. See also, infra, text accompanying notes 232-233.

127 Johnson, supra, note 121 at 1-276. Further discussion of this incident is available for those with access to classified NORAD Technical Memorandum 81-S-3.

128 "Space Object Strikes Salyut Window", AvWk&SpTech (8 August 1983) 20.

129 "Soviets Conduct Unusual Manned, Unmanned Activities", AvWk&SpTech (7 September 1987) 29.

allowed the booster to scrape along the bottom of the satellite, thereby causing the damage.[130]

The in-orbit fragmentation in November 1986 of the third stage of an Ariane rocket could have been caused by a collision. Scientists suggest that the destruction resulted from either an explosion of undissipated gases or a collision with an orbiting fragment.[131] Officials prefer the explosion theory; when computer analyses were conducted to determine whether the breakup was caused by space debris, no trackable debris was found in the area.[132] At present, the US National Aeronautics and Space Administration (NASA) and ESA are examining the rocket fragments for a definitive explanation. An abundance of evenly distributed, small chunks would indicate an explosion; larger pieces on trajectories skewed toward one direction would suggest an impact.[133]

(b) The Cascade Effect

Perhaps the most serious consequence of collisions with space debris is the cascade effect, first hypothesized in

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130 "TDRS Orbital Shift Delayed Pending Study", **AvWk&SpTech** (18 April 1983) 26-27.

131 "Ariane Booster Fragments in Space" (February 1987), **Satellite Telecommunications** 11. As a result of this explosion, the US government requested that a new study of space debris be conducted.

132 "Used Ariane Stage Explodes, Creating Space Debris Hazard", **AvWk&SpTech** (1 December 1986) 34.

133 DeMeis, **supra**, note 19 at 11.

1978.[134] Simply stated, cascading is a process by which space debris will become self-generating and therefore uncontrollable.

Proponents of the cascade effect argue as follows: As the number of space objects in Earth orbit increases, the probability of collisions between them also increases. Possibly well before the year 2000, collisions could produce new orbiting fragments (secondary debris), each of which would increase the probability of further collisions. When sufficient secondary debris has been generated, the debris flux will increase exponentially with time, even if no new objects are placed in orbit by man. Unless specialized launch constraints and operational procedures are implemented, cascading could lead in this century to the formation of a debris belt around Earth. Since only heavily protected spacecraft could survive such an environment, this belt could pose a significant problem during the next century.[135]

If this hypothesis is correct, describing secondary

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[134] In 1970, while investigating the collision danger to spacecraft posed by asteroids, the cascade effect was hypothesized to explain the formation of asteroid belts; see D.J. Kessler, "Estimate of Particle Densities and Collision Danger for Spacecraft Moving Through the Asteroid Belt" in T. Gehrels (ed.), Physical Studies of Minor Planets (Washington, DC: NASA, 1971) 595.

[135] Kessler and Cour-Palais, supra, note 7 at 707 and 724. See also, United Nations, Official Records, Committee on the Peaceful Uses of Outer Space [hereafter UN GAOR, COPUOS], Mutual Relations of Space Missions, A/AC.105/261 (7 December 1979) par 10 [hereafter Mutual Relations].

debris as "insidious"[136] and the "ultimate hazard of satellite break-up"[137] is not an over-reaction. The significance of the cascade effect is three-fold: (1) the occurrence of a few collisions could dramatically increase the severity of the space debris problem; (2) collisions and any ensuing cascading may make this problem unmanageable, since space debris is virtually impossible to remove,[138] and (3) the near-Earth environment could become so populated with space debris that LEO would be unusable, especially at its lower limits[139].

(c) Misinterpretation

As humanity pursues its adaptation to the outer space environment, collisions with space debris are inevitable. However, the intent of these impact events could easily be misinterpreted. For example, if a collision resulting in a loss of life were followed by hostility and suspicion among nations, plans for a rapidly expanding human presence in outer

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[136] Mendell and Kessler, **supra**, note 109 at 1.

[137] N.L. Johnson, **Space Environment Background Assessment**. Prepared for NASA Johnson Space Center in conjunction with US Army Strategic Defense Command (Colorado Springs, CO: Teledyne Brown Engineering, 1986) 2-9.

[138] R.C. Reynolds et al., "A Model for the Evolution of the On-Orbit Man-Made Debris Environment" (1983), 10 **Acta Astronautica** 479 at 481; also published in Kessler and Su, **supra**, note 1 at 102.

[139] R.C. Reynolds et al., "Man-Made Debris Threatens Future Space Operations" (September 1982), **Physics Today** 9 at 116 and Mendell and Kessler, **supra**, note 109 at 1. This possibility is a "worst-case" scenario.

space could be frustrated for decades, possibly generations, to come.[140]

If space debris were to strike an active payload, that collision could be mistaken for an armed attack or some other deliberate attempt to cause damage. Suppose, for example, that a fragment of space debris were to strike and destroy a satellite used for verification of arm's control agreements, detection of intercontinental ballistic missile launches or military communications. This collision could be interpreted as the deliberate use of a weapon, especially if the strike occurred shortly after an ASAT, SDI or other defensive weapon-related test in outer space. Fears of such a misinterpretation have been aroused on several occasions. Moreover, the risk of such an occurrence will increase as weapons-related tests involving collisions with targets continue.[141]

Misinterpretation could also occur on the re-entry of a collision-induced fragment into the Earth's atmosphere, since the final trajectory of a decaying, large space object is

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140 Wolfe and Temple, supra, note 83 at 2.

141 B. Jasani, "Military Uses of Outer Space" in Stockholm International Peace Research Institute, SIPRI Yearbook 1987: World Armament and Disarmament (London: Oxford UP, 1987) 57 at 67; UN GAOR, COPUOS, Physical Nature and Technical Attributes of the Geostationary Orbit, A/AC.105/203/Add.4 (18 May 1983) par 36 [hereafter 1983 Physical Nature], and SAB draft report, supra, note 3 at 4-5. Regarding weapons testing, see, supra, A/3(a)(i).

similar to that of a re-entering ballistic missile.[142] Therefore, if the debris fragment were large enough, it is possible that its re-entry could be mistakenly identified as a military offensive. As early as 1970, there have been instances when objects in orbit could have confused defense radars guarding against surprise missile attack.[143]

(d) Release of Contamination

Collisions between active payloads and space debris could release radioactive contamination and other various waste products into the outer space environment.

Active payloads with NPS on board are the prime source of radioactive contamination. Two types of NPS have been launched into outer space: radio-isotopic generators and nuclear reactors. Radio-isotopic generators are perhaps the simplest nuclear power supply, consisting of radionuclide fuels surrounded by energy conversion systems. The radio-

142 J.A. Howell, "The Challenge of Space Surveillance" (June 1987), **Sky & Telescope** 584 at 588. When a satellite de-orbits in this way, great precautions are taken to ensure that neither the United States nor the Soviet Union mistakes its identity, regardless of who launched the satellite; id.

143 C.S. Sheldon II and B.M. DeVoe, "United Nations Registry of Space Vehicles" (1970), 13 **Colloquium Law of Outer Space** 127 at 130. The US-USSR Nuclear Risk Reduction Centers could be used in the future to facilitate communications in order to prevent misunderstandings concerning unexplained incidents involving either nation's satellites or other space assets. At present, the purpose of the Center is to augment the superpowers' ability to reduce the risks of nuclear war, particularly as a result of accident, misunderstanding or a third-party nuclear terrorist threat designed to foment a US-USSR confrontation. See "Soviets Will Pay US for Risk Center Equipment", **AvWk&SpTech** (21 September 1987) 31.

isotope decays spontaneously, emitting ionizing radiation which is absorbed as heat and can be converted into other forms of energy. Nuclear reactors derive their thermal energy from the controlled fission of uranium-235 and are usually considered superior to radio-isotope generators for providing greater power levels. The reactor consists of an enriched uranium core with a reflector, producing heat for possible conversion to other forms of energy.[144]

The Soviet Union has 31 NPS satellites in orbit; US space plans call for the launch of nuclear reactors and rockets powered by nuclear engines.[145] A 1986 study indicated that 48 radioactive satellite components carrying more than one tonne of highly enriched uranium-235, plutonium-238 and assorted fission products are orbiting Earth. By the end of this century, it is estimated that there will be more than three tonnes of toxic fuel and fission products in orbit, unless there are setbacks in NPS satellite programmes.[146]

The majority of NPS satellites reside in the most densely populated regions of LEO (approximately 900-1,000 km), thereby

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144 UN GAOR, COPUOS, "Report of the Working Group on the Use of Nuclear Power Sources in Outer Space on the Work of Its Third Session", Report of the Scientific and Technical Sub-Committee on the Work of Its Eighteenth Session, A/AC.105/287 (13 February 1981) Annex II, par 7 [hereafter NPS Working Group report] and N.L. Johnson, "Nuclear Power Supplies in Orbit" (1986), 2 Space Policy 223 at 224-25.

145 "Reactors in Space: US Project Advances", The New York Times (6 October 1987) C1.

146 "Radioactive Space Debris Study Cites Hazards to Satellites, Earth", AvWk&SpTech (22 September 1986) 19 at 19-20.

enhancing the danger of collision with other Earth-orbiting objects. Destruction of an NPS satellite will not only make it impossible to dispose of the satellite in the future, but will also release radioactive contamination and radioactive debris fragments, threatening Earth and active payloads.[147] Such a collision could produce as many as one million radioactive particles of 1 mm or more in diameter. Some of these particles would be injected into orbits with perigees well below 1,000 km, regions which could be populated by large manned spacecraft.

If the active payload population continues to grow at present rates, the chance of a collision with an NPS satellite before re-entry from its storage orbit[148] is a "virtual certainty". Moreover, due to natural orbital decay, NPS satellites or their radioactive component parts, whether in operational or disposal orbits, will begin to enter lower altitude régimes after several hundred years. By then, this region may be populated by very large structures, both manned and unmanned. For example, the impact of a spent NPS fuel core with a space station "could be devastating", causing radioactive contamination in addition to structural damage,

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147 Id.

148 Storage orbits serve a warehousing function. To ensure that Earth is not exposed to a radiation hazard from the re-entry of NPS satellites, the Soviet Union places the NPS components in storage orbits when the satellite has completed its mission. When the risk of harm has passed, these components will be returned to Earth.

since the half-life of uranium-235 is in excess of 700,000 years.[149]

In addition to damage, the release of radioactive materials following a collision could affect the performance of the proposed US space-based radar, by disrupting the propagation of electromagnetic waves in the atmosphere.[150] Previous releases of radioactive contamination into the atmosphere have disturbed radio connections, altered the radiation situation of the Earth environment and produced an artificial radiation zone affecting the Van Allen belts.[151] Perhaps radioactive contamination in outer space would have analogous effects on space-based communications systems and orbital habitats.

Collisions with space debris could also result in releases of other contamination. Unusable waste by-products destined for Earth, quarantined microbiological organisms and used or contaminated material (eg, stored gases and rocket motor lubricant leakage) could be released, increasing the

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[149] Johnson, **supra**, note 144 at 230-31.

[150] "DNA Models Nuke Effects for Space Radars", **Military Space** (12 October 1987) 4.

[151] E.R.C. van Bogaert, **Aspects of Space Law** (Netherlands: Kluwer, 1980) 64. The three Van Allen belts, located between altitudes of 1,500-20,000 km, form a zone around Earth with particles charged with high energy. Their disturbance can influence the natural radiation fields of the Earth environment.

quantity of accumulating space debris and causing hazards to navigation, communication and health.[152]

(e) Alteration of Operations and Design

Risk of collisions with space debris is becoming a significant factor when considering space operations and the design of spacesuits and spacecraft.[153] Already, the potential hazard to humans and active payloads has resulted in the alteration of operations and design. Efforts to plan and implement these and future unanticipated changes require unbudgeted expenditures of time and money, shifting human and technological resources away from scheduled projects.

Space operations include satellite traffic management and satellite station-keeping procedures. Satellite traffic management operations in the United States include the examination of the orbit of every catalogued object prior to launching a new payload, in order to determine whether any space object will pass close to the new payload during its first few hours in orbit. Although comprehensive collision avoidance for all payloads throughout their active lives is currently beyond US capabilities,[154] management programmes may have to be modified if the quantity of space debris

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152 P. McGarrigle, "Hazardous Biological Activities in Outer Space" (1984), 18 Akron LR 103 at 114; M.J. Mackowski, "Safety on the Space Station" (March 1987), Space World 22 at 22-23, and Girata and McGregor, supra, note 86 at 326.

153 Temple, supra, note 101 at 6.

154 Johnson, supra, note 126 at 14.

increases as predicted. Currently, the US Space Command and NASA are working together to assess the feasibility of manoeuvring the proposed space station to avoid collisions.[155]

When satellites are designed, weight is the limiting factor. Therefore, these payloads are allocated carefully calculated quantities of fuel for station-keeping functions. The possibility that these space objects will have to consume fuel to avoid space debris upsets these calculations. When a collision occurs but does not damage the satellite, small changes in course may result,[156] also necessitating the use of allocated fuel reserves to steer the satellite back on course.

Space planners are primarily concerned with protecting the lives of those carrying out space activities -- astronauts on EVAs and crews manning STS orbiters and the future space station.[157] Since the risk of spacesuit damage is unacceptably high for prolonged operations, new suits are being designed to give greater protection against collision impacts. However, the additional degree of protection offered by these alterations still needs to be evaluated.[158] In addition, design of a Crew Emergency Rescue Vehicle (CERV) for use on

155 "Orbiting Junk Threatens Space Missions", **The New York Times** (4 August 1987) C1 at C3.

156 "The Orbiting Junkyard" (April 1982), 16 **Futurist** 77.

157 Frederick, **supra**, note 15 at 17.

158 Temple, **supra**, note 101 at 8 and DeMeis, **supra**, note 19 at 10.

the space station will take debris-related hazards into consideration.[159]

Active payloads are designed to withstand impacts from the natural meteoroid flux, not space debris.[160] At relative velocities of 10 km/sec, even millimetre-sized debris particles cannot be ignored.[161] At present, the current level of significant or trackable space debris is of sufficient hazard that it must be considered by the designers of large structures such as the space station[162] and the advanced X-ray astronomy facility[163]. Designers are shielding the planned space station to withstand the impact of minor space debris.[164] However, the amount of shielding which can be added to a spacecraft is limited. For example, protection requirements against even a 100-gm impact are so severe that a space station may have to accept a much higher probability of

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159 Mackowski, supra, note 152 at 22-23.

160 Kessler and Cour-Palais, supra, note 7 at 707.

161 J.A. Sanguinet, "Satellite-Based Instrument Concepts for the Measurement of Orbital Debris" (1985), 5 Advances Space Res 59 at 59.

162 The possible collision between space debris and the space station has been an important design consideration since at least 1984; "Station Likely to Be Hit by Debris", AvWk&SpTech (17 September 1984) 16.

163 Temple, supra, note 101 at 4.

164 "Orbiting Junk Threatens Space Missions", The New York Times (4 August 1987) C1.

impact damage or be restricted to orbits where the space debris flux is lower.[165]

Other design alterations include those already made to rockets to reduce the chance that a collision with space debris will cause an explosion.[166] Work is also under way to determine the possible effects of space debris on space telescopes. Then, satellite observatories will be able to plan ahead and avoid the damage which will likely be suffered by the Hubble Space Telescope.[167]

2. INTERFERENCE

The quantity of space debris of various sizes accumulating in outer space could interfere with scientific, commercial and military activities. Interference with space activities could also result in misinterpretation.[168]

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165 Kessler and Cour-Palais, supra, note 7 at 723.

166 "Orbiting Junk Threatens Space Missions", **The New York Times** (4 August 1987) C1.

167 "Hubble Trouble?" (January 1987), **Sky & Telescope** 31. Scheduled for launch in 1989, there is a 1 per cent chance that the Hubble telescope will be destroyed by a collision with space debris during its 17-year projected lifetime; S. Van Den Bergh, "Century 21: The Age of Space Junk?" (July 1987), **Sky & Telescope** 4. However, the telescope is too far along in its development to incorporate structural alterations which would protect it from collisions; "Debris in Space Presents an Increasingly Difficult New Dilemma for Scientists", **Satellite News** (10 August 1987) 7.

168 See, **infra**, B/1(c).

(a) Scientific Activities

Space debris may interfere with the acquisition of scientific data from experiments based in space or on Earth.

Space-based interference may cause the "graceful" degradation which damages without destroying the surfaces of optical instruments and solar panels.[169] This surface erosion could impair the accuracy of scientific data or eliminate its collection. Gases, solid particles and glow released as by-products of STS orbiter operations could also affect future scientific observations from orbiting space vehicles.[170]

Solid microparticulate matter is especially troublesome. It can settle out on optical surfaces, reducing their transmission, and can scatter unwanted light from the Sun or Earth into the line of sight of a telescope.[171] In the past, scientists have expressed concern about the impact that this particulate interference could have on observations from future astronomy-oriented payloads[172] such as the Hubble Space Telescope. Of special interest are the exhaust clouds of aluminum oxide given off when second-stage SRMs are fired.[173] These clouds, existing for as long as two weeks after the

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[169] See Table 1, supra, text accompanying note 100.

[170] See, supra, A/4(c).

[171] Green, supra, note 95 at 504.

[172] "Contamination Threatens USAF Payload", AvWk&SpTech (24 May 1982) 63.

[173] See, supra, A/4(a).

rocket firing,[174] significantly affect meteoroid measurements in Earth orbit and stratospheric cosmic dust collection experiments, by altering the very desirable "clean" environment of space.[175]

Gases (eg, water vapour) can absorb light from astronomical sources, giving false, partly attenuated spectra (visible and infra-red). Spaceglow may stand in the way of a telescoping line of sight, adding spurious signals and limiting the sensitivity of astronomical or Earth observations.[176]

The large concentration of space debris in LEO may also cause interference with radio signals used by various radio astronomy space missions.[177]

Earth-based scientific activities also suffer from interference with space debris. Inactive payloads and rocket fragments may disturb the receiving frequency bands in which sensitive instruments (eg, radio telescopes) are operating,

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174 Marshall, supra, note 7 at 425.

175 A.C. Mueller and D.J. Kessler, "The Effects of Particulates from Solid Rocket Motors Fired in Space" (1985), 5 **Advances in Space Res** 77 at 77. Analysis of the Microabrasion Foil Experiment flown on the third STS orbiter flight suggests that aluminum oxide contamination "is not a serious threat to the collection and analysis of at least the smaller craters" in the 5-microgram thick foil used for cosmic dust collection; W.C. Carey et al., "Space Shuttle Microabrasion Foil Experiment (MFE): Implications for Aluminum Oxide Sphere Contamination of Near-Earth Space" (1985), 5 **Advances in Space Res** 87 at 87.

176 Green, supra, note 95 at 504.

177 I.A. Vlasic, "Disarmament Decade, Outer Space and International Law" (1981), 26 **McGill LJ** 135 at 195.

thereby preventing clear reception of celestial radio signals.[178] Space debris regularly disfigures photographs of distant stars and galaxies, taken with ground-based telescopes.

Already, space debris has prompted false discoveries: What were thought to be distant pulsing stars sending out powerful but rare optical flashes, turned out to be reflections off the solar panels of dead, tumbling satellites.[179] Space debris, among other phenomena, has also been mistaken for unidentified flying objects.[180] Although these "discoveries" lack scientific rigour, they are noteworthy since they indicate that space debris may interfere with naked-eye observations of the sky and beyond.

In the future, threats of interference may come from more diverse sources. Proposed space-based projects have included a plan to launch a ring of 6-metre-diameter aluminum-coated spheres into an 800-kilometre orbit. Such a ring of light would do incalculable harm to astronomy, causing a loss of possibly 1 per cent of all observations due to individual spheres passing through the fields of view of telescopes, and destroying or severely damaging quite a few types of detectors

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178 M. Benko et al., Space Law in the United Nations (Netherlands: Nijhoff, 1985) 140.

179 "Orbiting Junk Threatens Space Missions", The New York Times (4 August 1987) C1 at C3.

180 J. Mahoney, "Who's Zoomin' Who?" (Fall 1987), 18 York University Alumni News 8.

by even a brief exposure to such a brilliant source of light. Another proposal was the art satellite project, a highly reflective sail with a surface of 1,800 sq m. Its brightness could have exceeded that of the full Moon, blotting out the faint stars and distant galaxies which are of greatest interest to many astronomers.[181]

In response to this potentially harmful interference with astronomical observations, concerned scientists have formed an organization to counter the proliferation of space debris. One of their targets is Celestis Group Inc., a Florida-based corporation which plans to launch cremated human remains into polar orbits using shiny canisters the size of lipstick tubes.[182]

(b) Commercial Activities

Interference with commercial activities by space debris is dominated at present by the problem of congestion. In the future, space debris could interfere with the effective functioning of proposed solar power satellites and other space-based facilities and could possibly disrupt manned spacecraft operations.

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[181] Van Den Bergh, supra, note 167 at 4 and "Debris in Space Presents an Increasingly Difficult New Dilemma for Scientists", Satellite News (10 August 1987) 7 at 8. These projects have since been withdrawn; Van Den Bergh, id.

[182] Id. Celestis Corp. has tentative approval from the US Department of Transport for its plan; Van Den Bergh, id.

Congestion (or crowding) of outer space is an obvious risk posed by space debris to commercial space activities. When applied to the vast expanses of outer space, the use of "congestion" would be absurd if present and future space activities were evenly distributed throughout this seemingly infinite environment. However, the largest number of active payloads is located in the vicinity of Earth.[183] It follows, therefore, that the bulk of space debris is located in LEO and GEO, those areas of near-Earth space beginning to experience congestion.

Several manned missions have confirmed the existence of congestion in LEO. In March 1965, Soviet cosmonauts reportedly cried out in surprise on viewing a man-made satellite passing within 1.5 km of their spacecraft. Three months later, US astronauts reported seeing and photographing several satellites while in orbit.[184] The crew of the STS-9 Spacelab mission observed an unidentified satellite pass in the vicinity of their spacecraft.[185] It has been calculated that an STS orbiter, at an altitude of about 270 km on a four-day mission, would come within 200 km of some 67 space objects

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183 Vlasic, supra, note 117 at 195.

184 Hall, supra, note 7 at 329.

185 It is unclear from the information available whether the sightings in these three incidents were of active or inactive payloads.

larger than 1 metre.[186] Future accumulations of space debris can only exacerbate this problem.

In GEO, satellites sharing the same nominal orbital position come close together periodically at the borders of their slots. In a sample of GEO encounters for 21 satellites during a six-month period in 1981, there were 120 predicted encounters in a 50-km "near-miss" distance. Several close approach predictions were in the 1-5 km range, necessitating collision avoidance manoeuvres. For example, FLSATCOM 1 (1978-016A), a US military satellite, had eight close encounters with SBS 1 (1980-091A), five of them between 2.6-6.0 km, and five additional near misses with other satellites. In May 1980, FLSATCOM 1 was forced to take evasive action to avoid colliding with IMEWS-4 (1973-040A), another US military satellite.[187] Again, increasing amounts of trackable and untrackable space debris will only make this problem worse.

Congestion in heavily used regions of space could lead to interference with the transmission of satellite telecommunication data. Reflections off a debris fragment nearing an active telecommunications satellite could interfere with the latter's attitude control sensors, causing altitude distur-

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186 R.T. Swenson, "Pollution of the Extraterrestrial Environment" (1985), 25 **Air Force LR** 70 at 72 and Schefter, supra, note 121 at 50.

187 1983 Physical Nature, supra, note 141, par 33.

bances and breaks in service.[188] Such close approaches could also unintentionally jam radio frequencies, thereby disrupting satellite operations.

Frequent acts of congestion would almost certainly have adverse effects for commercial telecommunication satellite operators. Corporate profits could be affected. Business could be lost if frequency interference or altitude changes regularly interrupted data transmission. Costs could increase in order to recoup losses occasioned by unplanned fuel expenditures for collision avoidance. In the latter instance, too many unplanned avoidance manoeuvres could reduce limited station-keeping fuels to such an extent that either the operational life of the satellite would be decreased or the satellite would not be boosted into a disposal orbit,[189] thereby adding to the congestion.

Solar power stations will need a clear path for transmission of their energy beams from space to ground receiving

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[188] UN GAOR, COPUOS, **The Feasibility of Obtaining Closer Spacing of Satellites in the Geostationary Orbit**, A/AC.105/340/Rev.1 (22 April 1985) par 50 [hereafter Closer Spacing report].

[189] Disposal orbits are analogous to Earth-based junk yards. When an operator has no further use for an active payload, particularly telecommunication satellites in GEO, these payloads are boosted from their operational orbit into a higher orbit. Boosting from GEO frees up its limited number of orbital positions for further use. It is believed that disposal orbits will not interfere with active payloads in GEO or other operational orbits.

It has also been proposed that nuclear wastes produced on Earth be placed in disposal orbits; see D. Lunan, "Nuclear Waste Disposal in Space" (1983), 36 **J Brit Interplanetary Soc** 147.

stations. Preventing undesirable reflections from space debris might require sophisticated co-ordination. Also, space manufacturing facilities would require free paths between the celestial body being tapped for material and the facility's mass catcher. These trajectories should not be traversed by another body during operation of the mass catcher.[190]

Finally, a recent and unique incident indicates the extent to which space debris could interfere with manned space operations. On 5 April 1987, the Soviet Union planned to dock the Kvant astrophysics module with the Mir space station. This attempt was unsuccessful, as was a similar effort four days later, due to the failure of the connection between the two spacecraft to seal itself completely by just a few centimetres. A third attempt succeeded, following an unplanned EVA to inspect Kvant's docking unit. During the EVA, the cosmonauts discovered a 40-centimetre square, white cloth object wedged inside the module. After the object was removed, the docking was completed. The object may have been a protective covering, label or bag which was mistakenly left on Kvant by the ground crew. To date, the exact nature of the object and its origin have not been identified with absolute certainty.[191] Therefore, the possibility exists that the

190 Mutual Relations, supra, note 135, pars 17-18.

191 "Soviets Dock Module to Mir Following Aborted Attempt", **AvWk&SpTech** (13 April 1987) 27; "Piece of Cloth on Space Craft Puzzles Soviets", **The Globe and Mail**, National Edition (15 April 1987) A8; "EVA Performed to Dock Kvant to Mir", **AvWk&SpTech** (20 April 1987) 21, and "Two EVAs Allow Mir

object's origin was outside the module, floating in space. But even if were not, interference by space debris with the mechanical operation of manned spacecraft could occur in a similar manner in the future.

(c) Military Activities

The military has expressed concern that microparticulate matter in outer space could interfere with its planned activities. As a result of contamination observed by elements of the OSS-1 payload flown on the third STS orbiter mission, USAF officials feared that data from both their cryogenic (very low temperature) infrared radiance instrumentation and horizon ultraviolet programme sensor could be spoiled. Some scientists believed that solid particle interference could render the former payload useless, since cryogenic infrared payloads, designed to track other bodies in space, would either tend to lock on to space debris or have their data dominated by the debris.[192]

3. MILITARY USES

Due to its destructive nature, the possibility exists that space debris could be harnessed for military uses. Prior to outlining these applications, a brief description of

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Cosmonauts to Install Third Solar Array", AvWk&SpTech (22 June 1987) 35.

192 "Contamination Threatens USAF Payload", AvWk&SpTech (24 May 1982) 63.

collision mechanics is necessary in order to appreciate the military potential of space debris.

(a) Collision Mechanics

Thus far, space debris has been presented as individual objects of various sizes, ranging from rocket bodies to microparticulate matter, drifting in a variety of orbits through outer space. Although this perception is not incorrect, it is incomplete; space debris also may be viewed as clouds of solid particulate matter.

Individual pieces of space debris have an average velocity of 10 km/sec on impact. Therefore, two objects will be subjected to high instantaneous pressures on contact, with the ensuing hypervelocity shock waves causing melting and possible vaporization in the immediate region of the impact. Either a crater or hole will then be formed; the resulting molten ejected mass will coalesce into more or less spherical particles. The combination of shock waves, particle fragments hitting other surfaces and vapour pressure may cause fragmentation outside the cratered region, possibly leading to the destruction of both objects.[193]

Debris clouds are formed by collisions or explosions. In the 1987 SDI Delta-180 space intercept and collision test, it was demonstrated that physical contact between two objects is not necessary to transform them into debris clouds. Rather,

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193 Kessler and Cour-Palais, supra, note 7 at 715.

the hypervelocity shock waves resulting from the initial contact may move through both objects, pulverizing them before contact is made. The result is the formation of two debris clouds, each passing through the other and into different orbits.[194]

There are three stages in the evolution of a debris cloud. First, the particles form a sphere; then, the sphere encircles Earth at a fixed inclination in the shape of a torus with two pinch points.[195] The solid particles are randomly distributed throughout the torus, with an initial concentration at the pinch points. Finally, due to several perturbation factors, the torus widens at the pinch points until it becomes a steady-state, evenly distributed belt or shell of debris, centred about the Earth's equator.[196]

Computer models estimate that debris clouds could contain between 200 to 3,000,000 fragments, with particle sizes

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[194] "SDI Delta Intercept Yields Data On Space Collision Shock Waves", **AvWk&SpTech** (8 June 1987) 26-27.

[195] A torus is a three-dimensional band. The pinch points result from the orbital intersections of the debris particles where the cloud volume vanishes, due to the absence of gravitational geopotential and atmospheric perturbations; SAB draft report, **supra**, note 3 at 50.

[196] N.L. Johnson and D.S. McKnight, **Artificial Space Debris** (Malabar, FLA: Orbit Books, 1987) 55-56; V.A. Chobotov, "Dynamics of Orbiting Debris Clouds and the Resulting Collision Hazard to Spacecraft". Paper IAA-87-571, prepared for presentation at 38th Congress of the IAF, Brighton, 10-17 October 1987, at 5, and S-Y Su, "Orbital Debris Environment Resulting from Future Activities in Space" (1986), 6 **Advances in Space Res** 109. Regarding perturbations, see, **infra**, text accompanying notes 219-223.

ranging from 0.1 to 120 cm in diameter.[197] Actual measurement of debris clouds has revealed that they may contain particles as small as 1-10 micrometres.[198] Tests indicate that only about 30 per cent of debris cloud particles are relatively long-lived.[199]

Recent studies also indicate the possibility that a different type of debris cloud could be formed by the effect of electrodynamic forces on small aluminum oxide particles ejected into the magnetosphere from SRM burns. The smallest particles (0.1 micrometre) would be ejected out of the magnetosphere into hyperbolic orbits. The larger particles (about 1 micrometre) would either drift away from or toward synchronous orbit. If the latter is the case, these grains would form a stable ring.[200]

Generally, the collision hazard posed by debris clouds varies with their density. For example, if there is a low density of debris (one particle/km-squared), the daily chance of impact is 0.0032, the monthly chance is 0.092 and the yearly chance is 0.69. Debris distributions with higher

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197 Chobotov, ibid., at 4.

198 Johnson, supra, note 126 at 17-18.

199 SAB draft report, supra, note 3 at 50.

200 M. Horanyi and D.A. Mendis, "Space Debris: Electrodynamic Effects" (1986), 6 **Advances in Space Res** 127 at 127 and 130.

numerical densities would have correspondingly higher impact rates.[201]

The risk of a debris cloud colliding with a spacecraft is proportional to the projected area of the spacecraft passing through the cloud and the distance travelled through the cloud, as well as the debris density of the cloud. The greatest hazard occurs at or shortly after cloud formation, when the cloud volume is small and its density large. The hazard decreases with time as the torus circumscribes Earth. The collision hazard is reduced to a minimum when the cloud reaches its steady-state condition.[202]

(b) Military Applications

The very real possibility of the military use of space debris is emphasized by the inclusion for the first time of a section on collisions with space debris in the chapter on the military uses of space in the 1987 edition of the annual yearbook of the Stockholm International Peace Research Institute.[203] In the United States, outer space is recognized as a medium in which military operations in support of national security can take place and from which military space

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[201] J.R. Michener, "Orbital Weapons Systems: Requirements, Countermeasures and Offensive Capabilities Creating a Cost-Effective(?) Defense?" (1987) 7.

[202] Chobotov, supra, note 196 at 5 and 7 and SAB draft report, supra, note 3 at 50.

[203] Jasani, supra, note 141 at 66-67.

functions can be performed.[204] It may be expected that space debris policy will have a significant effect on US military strategy in the future.[205] Military strategists there have already suggested that an easy way to destroy an "enemy" satellite "is to leave a trail of gravel in its path".[206]

Space debris viewed either as individual objects or clouds could have military applications, depending on the objective of the military action. Planned collisions between space debris and military targets could cause loss or damage. Individual objects have the advantage of size. Debris clouds have the advantage of density, making them useful not only for inflicting damage, but also for interference and camouflage purposes.

Space debris would be an effective countermeasure against space platforms in polar orbit, since each piece of debris has an energy potential of more than 15 times that of dynamite. The realization that space debris might be used as an offensive weapon would necessitate expansion of platform bumper

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[204] As of 25 September 1987, there were 337 operational satellites in outer space. Of the 129 US satellites, almost half were military. Of the 146 Soviet satellites, about two-thirds were military; J.E. Pike and M. O'Gorman, **What's Up in Space: Operational Satellites on the Anniversary of Sputnik I** (Washington, DC: Federation of American Scientists, 1987) 1. In GEO, more than a third of all active payloads are used for military purposes. This proportion could increase in the future as more and more countries perceive the need for military communication and verification satellites; 1983 Physical Nature, supra, note 141, par 35.

[205] Wolfe and Temple, supra, note 83 at 7.

[206] "The Orbiting Junkyard" (April 1982), 16 **Futurist** 77.

shields to ensure that any space debris would hit them. At the same time, this additional weight would make the platform less manoeuvrable, leaving its unshielded areas more vulnerable to impacts. Space debris striking the shields would rapidly create secondary debris which would in turn create more debris. Debris fragments which either directly strike the platform or successfully penetrate its shields could detonate the high energy solid fuel motors. Such an explosion would transform the platform into a mass of intersecting, colliding debris clouds in approximately polar orbit, thereby posing a major threat to other platforms and rendering all of near-space unusable. Moreover, placement of space debris to achieve these ends is very cost effective.[207]

Space debris could also be deliberately introduced into outer space to deny access to a particular orbital region. For example, one nation might decide that certain regions of space are more valuable to its enemies than to itself and would be willing to deny its use to anyone by littering these areas with so much space debris that entering them would be dangerous.[208] In addition, the calculated placement of space debris could interfere with certain surveillance activities. The United States may be concerned that space debris resulting

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[207] Michener, supra, note 201 at 7-9.

[208] Reynolds, supra, note 139 at 117 and Oberg, supra, note 105 at 43.

from the accidental 1986 Ariane launch explosion,[209] is in the path of its only photo-reconnaissance satellite in orbit.[210]

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209 See, supra, text accompanying notes 131-133.

210 Jasani, supra, note 141 at 66. On 26 October 1987, the USAF launched a "classified military payload" which is most likely a similar photo-reconnaissance satellite; "Successful Titan Launch Ends 18-Month Grounding", **Satellite News** (2 November 1987) 1-2. This successful orbital placement may alleviate US concern, assuming that the new satellite's trajectory avoids the Ariane detritus.

C/ LOCATIONS OF SPACE DEBRIS AND ITS DETECTION

In order to develop the most effective remedial measures for combatting the space debris problem, space planners must determine as accurately as possible the probability that a debris risk event will occur. Before the hazard posed by space debris to space activities can be stated precisely, it is necessary to know where debris objects are and how to find them. Since the ability to detect space debris varies with the location and size of the debris objects, the various regions in outer space where space debris is found will first be examined. Then, the facilities and the equipment used to detect, track and identify space debris will be discussed.

1. LOCATIONS

Space debris is found in four basic regions of outer space: LEO, the geostationary transfer orbit (GTO), GEO and beyond GEO. Discussion will be limited to the first three areas, as most space activities take place in them.[211] Since the quantity, relative velocities and orbital behaviour of space objects vary significantly according to the region in which the space objects are located,[212] the physical nature

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211 However, it should be recognized that space debris created beyond GEO could pose problems not only to humankind, but also to outer space per se, other celestial bodies and any extraterrestrial life.

212 N.H. Fischer and R.C. Reynolds, "Threat of Space Debris" (Columbus, OH: Battelle's Columbus Laboratories) 397. The major differences between GEO and LEO are (1) the number of space objects in GEO is much smaller; (2) the relative velocities of space debris in GEO are much less -- 40 m/sec as

and technical attributes of each of LEO, GTO and GEO will be discussed separately.

(a) Altitude, Inclination and Orbital Perturbations

A space object is located in space according to its altitude and inclination. Altitude is calculated according to the height of the object above Earth. Space objects in LEO may be found anywhere from 200-4,000 km, while those in GEO maintain an altitude of about 35,800 km. As of January 1986, 83 per cent of the approximately 5,900 known space objects resided in orbits with a mean altitude below 6,000 km.[213] The most densely populated region of outer space is between 500 and 1,000 km, with another high-density peak occurring at 1,450 km. Two smaller peaks are found at 3,700 km and in GEO. The latter is a special case, since the density there is high and growing and the relative positions of satellites are fixed.[214]

Inclination is measured east to west from 0 degrees at the equator through 90 degrees at the North Pole to 180 degrees at the equator. Space objects tend to cluster at

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opposed to 7 km/sec in LEO; (3) objects in GEO are less easy to observe, so much so that smaller debris objects, which would be observable if in LEO, cannot be detected, and (4) major active payloads in GEO can be controlled to avoid collisions in situations where conditions can be adequately predicted ahead of time; ibid., at 399.

[213] Johnson, supra, note 137 at 1-1.

[214] UN GAOR, UNISPACE 82, **Impact of Space Activities on the Earth and Space Environment**, A/CONF.101/BP/4 (30 January 1981) pars 80-81 [hereafter Impact of Space Activities].

various inclinations: 0 degrees latitude for telecommunication satellites in equatorial orbits; 30 and 60 degrees, due partially to the location of launch sites; above 60 degrees for certain communication satellites with highly eccentric orbits; about 80 degrees for coverage of all inhabited regions of the world, and between 95 and 105 degrees for sun-synchronous orbits.[215]

The maximum collision risk occurs between 950 and 1,000 km altitude. Inclinations where orbits are most likely to cross and therefore pose a risk of collision, include areas above the North and South poles, where all space objects in polar orbits must cross; GEO, and two bands in GEO between about 30-35 degrees north and south latitude, where eastward rotating satellites cross paths.[216] The spatial density of debris is highest at an altitude of 1,000 km, due to earlier breakups in the vicinity,[217] and at orbital inclinations of 0, 20, 40-50, 60 and 90 degrees[218].

The influence of orbital perturbations is significant. Without them, the orbit of a space object would remain unchanged forever. However, perturbative effects on active

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215 Ibid., par 78,

216 Johnson, supra, note 137 at 2-6 and Swenson, supra, note 186 at 72.

217 McKnight, supra, note 5 at 3.

218 "Debris -- The Pollutant of Outer Space (unpublished paper, Webster University, CO, February 1987) 5, citing D.J. Kessler, "The Space Debris Situation", NASA/Johnson Space Center, 1981.

payload and space debris trajectories are strong and must be taken into account. The dominant perturbations are due to the non-spherical shape of Earth,[219] which results basically in a change in orbit orientation relative to Earth; atmospheric

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[219] Earth is slightly pear-shaped, with the bulge at the equator, and is flatter at its poles. The pear shape can have an important effect on perigee height. In GEO, eg, it results in the movement of uncontrolled space objects up to 34 km above GEO when drifting westward and a similar distance below GEO when drifting eastward. These uncontrolled objects are attracted toward the two stable points in GEO at 105 degrees West and 75 degrees East; UN GAOR, COPUOS, **Physical Nature and Technical Attributes of the Geostationary Orbit**, A/AC.105/203 (29 August 1977) pars 12 and 13 [hereafter 1977 Physical Nature report]; Impact of Space Activities, supra, note 214, Annex I par 12, and L. Perek, "Telecommunication and the Geostationary Orbit: The Missing Regulation" (1983), 26 **Colloquium Law of Outer Space** 33 at 34.

The polar flattening (oblateness) makes a difference of about 20 km between the equatorial and polar radius of Earth. This oblateness has two effects: (1) the orbital plane rotates about the Earth's axis, so that for a satellite heading eastward, its orbital plane swings to the west up to 8 degrees/day, depending on the inclination of the orbit, and (2) the perigee latitude is continually changing, anywhere from 4-16 degrees/day, depending on the inclination of the orbit; UN GAOR, COPUOS, **Study on Altitudes of Artificial Earth Satellites**, A/AC.105/164 (6 January 1976) Annex I at 13 [hereafter Altitudes study] and Impact of Space Activities, **ibid.**, Annex I pars 8-11.

Sources differ as to which perturbations are most significant in LEO. One says those resulting from the non-spherical shape of Earth "are the most important". Another states atmospheric drag is the "dominant perturbation influencing the lifetime of a satellite in low altitude orbit"; see Impact of Space Activities, **ibid.**, Annex I par 13 and ESA, **Re-entry of Space Debris. Proceedings of an ESA Workshop held in European Space Operations Centre, Darmstadt, FRG, 24-25 September 1985** (Paris: ESA Publications, 1986) 77. Perhaps the former refers to the overall effect on movement of the space object from its original configuration, while the latter refers more specifically to calculation of space object re-entry.

drag,[220] which decreases orbital energy, reduces space object apogee and may ultimately lead to space object decay; and the forces of the Sun and Moon,[221] which not only may decrease the perigee height to such an extent that the space object hits

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220 If an orbiting space object comes within 1,000 km of Earth, it suffers an appreciable aerodynamic drag at its perigee and does not fly out to such a great distance at the other side of Earth. Therefore, its apogee decreases and the orbit becomes more nearly circular. After several years if the perigee is above 300 km, or only a few weeks if the perigee is below 150 km, the space object loses height catastrophically, encounters fierce aerodynamic heating and plunges to fiery destruction in the relatively dense atmosphere at heights below 90 km; Altitudes study, **ibid.**, Annex I at 1. See also, Impact of Space Activities, **ibid.**, Annex I pars 14-17. Regarding the effect of atmospheric drag in LEO, see Kessler and Cour-Palais, **supra**, note 7 at 725-30.

221 Luni-solar perturbations include gravitational effects and solar radiation pressure. The Sun and Moon exert small gravitational attractions on space objects, pushing them out of their orbital planes. In LEO, lunar gravity is about twice as effective as solar gravity, producing small oscillatory changes and displacing the space object by less than about 2 km during periods ranging from about 10 days to more than a year. However, gravitational attraction could build up over several years and become much larger than expected. In GEO, effects of gravitational attraction are considerable. The initial 0 degree inclination of the orbit of a space object increases by about 0.85 degrees annually until a maximum inclination of 14.6 degrees is reached after 26.5 years, at which time the inclination decreases back to zero. This attraction also causes a minor change in altitude and minor oscillations in longitude. See 1979 Physical Nature report, **supra**, note 219, pars 15-16 and Impact of Space Activities, **ibid.**, Annex I pars 19-21.

Solar radiation pressure (solar wind) is a radiation flux of high-energy particles from the Sun. This pressure results in a yearly oscillation in the perigee of the orbit, and varies with the area of the space object directed toward the Sun. The effect of solar radiation pressure can be appreciable, especially for space objects with high area/mass ratios (**eg**, balloons) and could alter the perigee altitude so that the lifetime of the space object is affected. See Impact of Space Activities, **ibid.**, Annex I pars 24-27 and Altitude Study, **ibid.**, Annex I at 25.

the dense atmosphere or even strikes the Earth's surface, but also could create a radiation hazard to persons and property.[222] In addition, the effect of the variation in solar activity, which increases atmospheric drag during peak activity periods,[223] must also be considered.

(b) Low-Earth Orbit (LEO)

LEO is a spherical shell, bounded below at about 200 km by the Earth's atmosphere and above at about 4,000 km by the Van Allen belts. Space objects cannot operate below 200 km due to atmospheric drag, while those operating above ap-

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[222] G. Janin, "How Long Do Our Satellites Live?" (1986), 45 ESA Bulletin 34 at 35. Other perturbations which exhibit a small effect on space object perigees include charged drag, by which the accretion of ions and electrons may change the cross-sectional area of a space object; solar radiation reflected from the Earth's surface; Lorentz force, resulting when an electrically charged space object moves in the magnetic field of Earth; the action of radiation arising as a result of the non-vanishing velocity of a space object, and the changing gravitational field of Earth, caused by tides in the solid Earth; Altitudes study, ibid., Annex I at 28.

[223] R.D. Eberst, "The Crowding Skies" (1982), 35 J Brit Interplanetary Soc 382 at 383. Solar activity, which varies over time, has its peak at what is called the solar maximum. The most recent solar maximum occurred between 1979 and 1981 and caused a considerable increase in atmospheric densities at space object altitudes, which in turn increased the atmospheric drag on all near-Earth objects. Many space objects therefore burnt up or decayed in the Earth's atmosphere far earlier than would have been expected if solar activity had remained constant. The unscheduled return to Earth of the Skylab space station is a prime example of the effect of solar activity; id. Atmospheric bulges produced by solar activity caused Skylab to re-enter the atmosphere, fragment and strike Earth in the vicinity of the South Pacific and Australia before NASA could devise a way of boosting it into a higher, more stable orbit; J.D. Scheraga, "Curbing Pollution in Outer Space" (January 1986), Technol Rev 8 at 9 and ESA, supra, note 219 at 82.

proximately 1,000 km must be designed to withstand the solar wind radiation which becomes trapped in the Earth's magnetic field.[224]

Since LEO is the easiest region of outer space to reach from Earth, it offers endless scientific, commercial and public use opportunities, providing the nearest orbital view of Earth, the clearest near window for observation of the universe, an experimental and manufacturing environment free from Earth's gravitational and atmospheric effects, and a shelter from the potentially destructive radiation produced by solar winds.[225] LEO already hosts a variety of space activities: research, military and commercial telecommunication satellites; storage orbits for space objects prior to their transfer to higher orbits,[226] and temporary domicile for

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[224] Mendell and Kessler, supra, note 109 at 3.

[225] National Commission on Space, **Pioneering the Space Frontier** (NY: Bantam Books, 1986) 81. The ability to withstand the effects of solar radiation is particularly important for manned operations such as space stations; Mendell and Kessler, **ibid.**, at 3. The shelter provided by LEO is especially effective between 200-600 km. Due to the shielding provided by the Earth's magnetosphere, radiation in this region is almost negligible; Office of Technology Assessment, **Civilian Space Stations and the US Future in Space** (Washington, DC: GPO, 1984) 50. The US-initiated international space station (USISS) is expected to orbit at an inclination of 28.5 degrees and at an altitude of about 350 km (220 nautical miles); "Fixes to Space Shuttle Hardware, Management Reach Critical Stage," **AvWk&SpTech** (4 May 1987) 78 at 79. Even so, the cumulative radiation dose is perceived as limiting crew duty cycles and total career time in space; Mendell and Kessler, **id.**

[226] In addition to being used for storing NPS elements, **supra**, note 148, storage orbits are used to warehouse communication satellites prior to their use, in order to save the

humans launched into orbit. Eventually, it will contain permanent human structures such as space stations.[227] In the United States, LEO is also seen as an efficient location for an infrastructure for servicing satellites in GEO and for launches from Cape Canaveral into the lowest energy orbit.[228]

It is becoming increasingly apparent that there should be serious concern for space debris in LEO.[229] The majority of man-made objects residing there are debris.[230] Generally, for space systems operating in orbits of 500-2,000 km, a persistent background of space debris will be encountered.[231] The most densely populated region of LEO is between 900-1,000 km, with heavy space debris concentrations at around 1,400 km, due to the Delta rocket explosions,[232] and at 800 km, possibly as a result of Soviet ASAT tests[233]. Since space debris

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expense of separate launchings and to ensure satellite availability if necessary.

227 Mendell and Kessler, supra, note 109 at 1-3.

228 Civilian Space Station, supra, note 225 at 50.

229 Reynolds, supra, note 138 at 749.

230 R. Kling, "Evolution of an On-Orbit Debris Cloud" (1986), 6 Advances in Space Res 99 at 99.

231 Edgecombe, supra, note 97 at 225.

232 See, supra, text accompanying notes 61-65.

233 L. Sehnal, "Probability of Collisions of Artificial Bodies in the Earth Environment" (1985), 5 Advances in Space Res 21 at 24 and H. DeSaussure, "The Application of Maritime Salvage Law to the Law of Outer Space" (1985), 28 Colloquium Law of Outer Space 127 at 130-31. See also, supra, text accompanying notes 40-55 and 217.

deposition is essentially an irreversible act, continued deposition increases the debris population. With larger space objects and longer orbital durations being discussed, the probability of collisions between these objects and a debris fragment becomes large.[234] Already, space debris is increasingly being seen as a substantial hazard to USISS.[235]

Cascading, the uncontrolled self-generation of space debris,[236] could have a particularly destructive effect in LEO, especially in its lower, more active region. Although atmospheric drag cleanses the lower orbital regions of space debris, any low-altitude particles which do decay in the atmosphere are being replaced constantly by space debris falling from higher altitudes.[237] If cascading begins, LEO will be plagued by an unending, continually increasing amount of space debris. In the end, LEO could be rendered virtually useless: shielding requirements would result in space objects too heavy to be launched from Earth; additional costs for properly shielding objects built in space would likely not be economically justifiable to government and corporate sponsors, and any objects which were or would be in LEO would be highly vulnerable to collisions.

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234 Reynolds, supra, note 138 at 749.

235 C.Q. Christol, "Space Stations: Political, Practical and Legal Considerations" (1984), Hastings Int'l & Comp LR 521 at 535.

236 See, supra, B/1(b).

237 Schefter, supra, note 121 at 50.

(c) Geosynchronous Transfer Orbit (GTO)

GTO may be considered a utility orbit, since it does not contain operational space objects. Its prime significance to space planners lies in the fact that objects in GTO pass through GEO, increasing the collision hazard there. However, space debris in GTO is important in its own right: It poses the same debris-related risks facing activity-based orbits and pollutes the outer space environment per se.

GTO is an elliptical orbit used during the process of inserting space objects into GEO. The space object is first placed in LEO by an expendable launch vehicle (ELV) or by deployment from the payload bay of an STS orbiter. Then, the space object is inserted into GTO by an upper stage rocket such as a PAM (payload assist module) or IUS. On separation from the upper stage, the space object coasts up to its apogee in GEO where an apogee kick motor circularizes its orbit. All spent upper stages, associated operational hardware and aluminum oxide particulate matter from SRM burns orbit in GTO.[238]

Objects in GTO have apogees near 35,780 km and perigees of about 300 km. Since GTO is a stable orbit, objects in it have lifetimes varying from a few months to more than 10

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[238] B. McCormick, "Collision Probabilities in Geosynchronous Orbit and Techniques to Control the Environment" (1986), 6 **Advances in Space Res** 119 at 123 and Moranyi and Mendis, **supra**, note 200 at 127. Apogee kick motors and their associated operational hardware orbit in GEO.

years.[239] The important perturbations affecting these lifetimes are the non-spherical shape of Earth, gravity of the Sun and Moon and atmospheric drag. These changes can drastically alter the orbits of space objects, either reducing lifetimes to a few months, thus removing them from consideration as a long-term debris hazard, or creating very long-life orbits.[240]

(d) Geostationary Orbit (GEO)

GEO is a member of the family of geosynchronous orbits. The term "geosynchronous" applies to all orbits having a period of rotation corresponding to that of Earth (about 23 hours, 56 minutes). Therefore, it applies not only to those space objects in GEO but also to those having orbits which are substantially eccentric (non-circular), inclined (non-equatorial) or both. From Earth, a geosynchronous space object will appear to describe a single or double loop about a point on the equator once every 24 hours.[241]

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[239] McCormick, id., and Janin, supra, note 222 at 36.

[240] Fischer and Reynolds, supra, note 212 at 399. See also, supra, text accompanying notes 219-223.

[241] Closer Spacing Report, supra, note 188, par 21 and UN, UNISPACE 82, Efficient Use of the Geostationary Orbit, A/CONF.101/BP/7 (16 January 1981) par 8. See also, Impact of Space Activities, supra, note 214, Annex I at par 28. Although no active payloads are currently in inclined or eccentric orbits, this technique has been proposed as a method of relieving pressure on GEO; see Closer Spacing report, supra, note 188, pars 88-90.

If it is assumed that Earth is an isolated, perfectly spherical spinning mass, then GEO may be defined as a geosynchronous circular orbit around Earth approximately 35,787 km above the equator. If the orbit were directly above the equator, a space object revolving from east to west, as Earth does, would appear from the ground to remain stationary. The advantage of such a perfectly stationary orbit is that it would be the only orbit in which a space object would have a constant view of a large area of Earth and would be continuously visible from any fixed point on the ground within that area. As a result, there would be no need for a fixed ground antenna being continually reoriented in order to track the space object.[242]

In practice, however, a space object cannot remain in such an orbit with a fixed orientation. Perturbations cause slow periodic variations in altitude and inclination of the orbit, resulting in movement of the space object from its desired geostationary position.[243] The primary perturbing factors in GEO are the non-spherical shape of Earth and the forces of the Sun and Moon.[244]

To counteract the perturbations, active payloads such as telecommunication satellites have station-keeping propulsion

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242 Closer Spacing report, **ibid.**, par 18 and Efficient Use of GEO, **ibid.**, par 6.

243 Closer Spacing report, **ibid.**, at par 19.

244 Perek, **supra**, note 219 at 34. See also, **supra**, text accompanying notes 219 and 221.

systems which maintain the satellites within a predetermined range close to their nominal orbital positions[245]. These station-keeping corrections must be applied periodically during the entire active life of the satellite. Otherwise, the natural forces would carry it outside the assigned range.[246]

Station-keeping manoeuvres greatly reduce, but do not eliminate, departures from the theoretically circular GEO. Due to perturbative forces, satellites in GEO are not stationary, but move in figure-8 patterns within the orbit volume. With current station-keeping technology, an active payload can be controlled so that it strays less than +/- 0.1 degree (75 km) from its nominal position.[247] Consequently, active payloads move through two bands about 150 km wide. One extends north and south of the equator; the other, in an east-west

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245 The nominal orbital position in GEO is assigned to a space station (a group of instruments mounted on a telecommunication satellite) by a member administration of the International Telecommunication Union (ITU) and notified to the International Frequency Registration Board (IFRB); 1983 Physical Nature report, **supra**, note 141, pars 4-5. Although telecommunication satellites must be separated to prevent radio frequency interference, there is no required minimum separation between orbital positions of space stations. Currently, several stations have been assigned the same position; ibid., par 32.

246 Closer Spacing report, **supra**, note 188, par 19 and 1977 Physical Nature report, **supra**, note 219, par 7.

247 The 1979 World Administrative Radio Conference (WARC) decided that in general the longitudinal station-keeping accuracy should be improved from +/- 1 degree to +/- 0.1 degree and should be effective no later than 1987; Closer Spacing report, **ibid.**, par 78.

direction along the orbital plane. Also, perturbations will cause variations in altitude of about 30 km. Therefore, the operational GEO should not be considered a circle, but rather a three-dimensional band or torus which is 150 km wide (north-south) and 30 km thick (altitude). An active payload will remain within a 150 km-long (east-west) segment of the band.[248]

GEO is a unique natural resource of vital importance for a variety of space activities, including communications, meteorology, broadcasting, remote sensing, data relay and tracking.[249] Today, the entire civil telecommunication satellite industry is located there, since only GEO can provide continuous contact with ground stations via a single satellite.[250] However, some areas of GEO are already crowded, due to the need to place telecommunication satellites in well-

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[248] Closer Spacing report, **ibid.**, par 20 and M.L. Smith III, "The Orbit/Spectrum Resource and the Technology of Satellite Telecommunications: An Overview" (1987), 12 **Rutgers Computer & Technol LJ** 285 at 287. In E.A. Roth, "The Geostationary Ring[:] Physical Properties and Collision Probability" (1984), 27 **Colloquium Law of Outer Space** 378 at 379, the thickness of the band is calculated to be 85 km.

[249] UN, UNISPACE 82, **Report of the Second United Nations Conference on the Exploration and Peaceful Uses of Outer Space**, Vienna, 1982, A/CONF.101/10 (31 August 1982) par 277 [hereafter UNISPACE 82 report].

[250] Pioneering the Space Frontier, **supra**, note 225 at 81 and House Comm. on Foreign Affairs, 97th Cong., 2d Sess., **Report on the Second UN Conference on the Peaceful Uses of Outer Space** (UNISPACE 1982), August 9-21, 1982 (Comm. Print 1983) 12.

defined orbital slots.[251] In the future, the congestion resulting from placing an increasing number of objects in a finite space is expected to become more severe.[252]

The physical basis of the space debris hazard in GEO arises from the effect of perturbations on space objects. All inactive payloads, operational debris and fragmentation debris are influenced by various perturbative forces,[253] a combination of which results in a long-term variation of their orbits. The pear-shape of Earth induces a drift in longitude. A space object outside the two stable positions at 75 degrees East (about the longitude of Bombay) and at 105 degrees West (about the longitude of San Diego) will oscillate slowly with a pendulum-like motion around the nearest stable point, with a period of about 2.25 years for small distances. The period increases with the maximum distance from the stable point.

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[251] U. Thomas, "Alternative Operational Modes and Cost of Removing Geostationary Satellite Debris" (1986), 6 **Earth-Oriented Applications of Space Technology** 307 at 307 and UNISPACE 82 report, supra, note 249 at 283. In May 1984, there were 115 operational satellites in GEO, with 160 in various stages of planning; Smith, **supra**, note 248 at 288. The four most intensively used areas of GEO are over the Indian Ocean (49-90 degrees E), Atlantic Ocean (1-35 degrees W) and Pacific Ocean, for communications between continents, and over North America (87-135 degrees W), for all North American communications; Closer Spacing report, **supra**, note 188, par 101 and Smith, **ibid.**, at 288, n.16.

[252] By September 1987, **eg**, the number of operational satellites in GEO had increased to about 130; calculated by the author, based on a graph in Pike & O'Gorman, **supra**, note 204 at 5. Also, it is generally expected that satellite sizes will increase considerably as antenna farms or perhaps even huge solar power satellites become operational; Thomas, **id.**

[253] See, **supra**, text accompanying notes 219-223.

The luni-solar perturbation influences mainly the inclination of the orbit. An inclination of initially 0 degrees will increase in about 27 years to nearly 15 degrees, thereafter returning to 0 degrees in the same period of time. Solar radiation pressure disturbs the eccentricity of the orbit, with the result that the distance of a space object from the centre of Earth varies daily by a considerable amount. Consequently, space debris objects will follow orbits of constantly changing dimensions and will cross the GEO band daily, at a different point every crossing, giving rise to the possibility of collisions.[254]

The collision hazard arises since the movements of active payloads are controlled through station-keeping manoeuvres, while those of space debris are not. For example, while an active telecommunication satellite will deviate from its nominal position by an altitude not exceeding +/- 15 km, an inactive telecommunication satellite will stray in altitude by about +/- 60 km from the nominal value, with an inclination exceeding 0.5 degrees.[255] In addition, an uncontrolled space object in GEO will cross the equator twice daily, while a

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[254] Roth, supra, note 248 at 379. See also, Closer Spacing report, supra, note 188, par 19. In the latter document, a distinction is made between non-functional satellites and other space debris. Since space debris is distinguished by the inability of a space object to control its movements, non-functional satellites are more properly classified as a type of inactive payload; see, infra, Chapter Two: A/1.

[255] Wiessner, supra, note 106 at 266.

controlled satellite maintains its position within the confines of the GEO band. Since a collision will occur if space debris and an active payload intersect at the same altitude, the presence of space debris makes GEO an "endless shooting gallery", with active payloads "sitting ducks", especially at its two stable points.[256] Moreover, GEO will not readily cleanse itself. Although all space debris will eventually decay, debris objects can have lifetimes in GEO in the order of 10 million years.[257]

2. DETECTION

Accurate calculation of collision probabilities requires detection of space debris, in addition to active payloads. Tracking equipment and related facilities provide the means by which space debris is located, identified, counted and tracked. The greater the technical and managerial efficiency of these detection networks, the better will be the abilities to reduce the collision hazard by predicting orbital paths, pinpointing space object re-entries, modelling future debris populations and determining the cause of fragmentation events.

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[256] D.H. Suddeth, "Debris in the Geostationary Orbit Ring: 'The Endless Shooting Gallery' -- The Necessity for a Disposal Policy" in Kessler and Su, **supra**, note 1, 349 at 356 and Wiessner, **id.** In 1982, in addition to 120 active payloads in GEO, the trackable space debris population included 41 inactive payloads, at least 25 Centaur upper stages, 10 ejected apogee kick motors and at least another 15 transtage upper stages, some of which may have exploded; Suddeth, **ibid.**, at 352 and 355 and Wiessner, **id.**

[257] Wiessner, **ibid.**, at 227 and Janin, **supra**, note 222 at 37.

(a) Equipment

Artificial objects in outer space can be divided into two groups, those which can be observed by tracking devices and those which cannot.[258] Generally, space debris larger than 1 cm can be detected from the ground; smaller debris pieces must be measured in space. Space debris objects between 0.1 mm and 1 cm are difficult to measure. While space objects smaller than 0.1 mm can be detected in space, the orbiting measurement devices cannot distinguish between natural micrometeoroids and space debris.[259]

The majority of equipment now used is ground-based and includes optical sensors, such as the Baker-Nunn cameras and the Ground-based Electro-Optical Deep Space Surveillance (GEODSS) system, and a radar sensor, the Perimeter Acquisition and Attack Characterization System (PARCS). All these instruments are operated by NORAD.

Optical sensors are currently the primary source of information. The Baker-Nunn cameras, the oldest of the optical sensors, first entered service in 1957 in time to observe Sputnik I.[260] They can track objects as small as 4 cm diameter at altitudes of less than 400 km and objects 2.5 m diameter in GEO.[261] This system relies on photographs which

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[258] Impact of Space Activities, supra, note 214, par 71.

[259] Kessler, supra, note 3 at 60.

[260] Howell, supra, note 142 at 586.

[261] Smith, supra, note 43 at 46.

must be developed and analysed before the information can be passed to NORAD. The Baker-Nunn cameras are being phased out, to be replaced by GEODSS.[262]

The GEODSS system is currently used to track space objects between 5,000-35,000 km altitude and is capable of detecting objects of 1 cm diameter in LEO and of 20 cm diameter in GEO. On completion,[263] the network of electro-optical observatories, spaced at roughly equal longitudes around the globe, will provide complete coverage up to and including GEO. Each observatory collects information by focusing sensitive low-light level television cameras through large astronomical telescopes, then feeding the light measurements in digital form to computers.[264] The Experimental Test System (ETS) of Lincoln Laboratory, designed and built as the prototype observatory of the GEODSS network, has been used to search for, detect and discriminate space debris at lower than

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262 Wirin, **supra**, note 10 at 5.

263 The four operational sites are in New Mexico, Korea, Hawaii and Diego Garcia in the Indian Ocean, with a fifth site planned for Portugal; see R.T. Herres, "Space Grows in Importance to National Security" (November-December 1986), **Defense** 86 17 at 22. Negotiations for the site in southern Portugal will delay completion of the network until at least US Fiscal Year 1995, leaving a major gap in eastern hemisphere deep space coverage until then; "USSPACECOM Pushes Deep Space Radar", **Military Space** (11 May 1987) 3.

264 Howell, **supra**, note 142 at 586; Wirin, **supra**, note 10 at 5, and Schefter, **supra**, note 121 at 51.

normal altitudes of 300-2,000 km in LEO as well as in GEO.[265] The improvements in space debris detection available with the GEODSS system have already been demonstrated by ETS when it determined that debris populations in LEO and GEO were much greater than had been previously expected.[266]

PARCS is NORAD's most powerful radar and can typically detect objects as small as about 8 cm in LEO. Past and continuing tests have shown an uncatalogued population between 7 and 35 per cent greater than the catalogued population.[267] PARCS was first used in 1984 to conduct a special test of small space objects at altitudes of 400 km and below. Six times as many uncorrelated objects normally seen by radar were detected, leading to the conclusion that there were even larger quantities of space debris at considerably higher altitudes. This system logged four times the catalogued population when it tracked a debris cloud formed by a satellite fragmentation.[268] NORAD is developing techniques to use

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[265] L.G. Taff et al., "Low Altitude, One Centimeter, Space Debris Search at Lincoln Laboratory's (MIT) Experimental Test System" (1985), 5 Advances in Space Res 35 at 35.

[266] See L.G. Taff, "Satellite Debris: Recent Measurements" (1986), J Spacecraft & Rockets 342 at 246; L.G. Taff and D.M. Jonuskis, "Results and Analysis of a Bi-Telescopic Survey of Low Altitude Orbital Debris" (1986), 6 Advances in Space Res 131 at 131-32; Taff, supra, note 265 at 35, and infra, text accompanying notes 354-356 and 388.

[267] SAB draft report, supra, note 3 at 10.

[268] Johnson, supra, note 126 at 15-16.

PARCS for routine sampling of space objects too small to be included in the NORAD catalogue.[269]

The first space-based sensing device providing an opportunity for space debris observation was the Infrared Astronomical Satellite (IRAS). Launched in 1983, IRAS can detect objects of 1 mm diameter at a range of 100 km and of 1 cm diameter at a range of 1,000 km,[270] thereby improving current operational ground-based capabilities. In addition, IRAS overcomes constraints of optical and radar sensors. For the latter, the smallest object observable is in the order of centimetres; the former are severely limited by local weather and particle lighting conditions. The usefulness of this system is limited, since IRAS is not part of NORAD's operational system.[271]

To conduct comprehensive hazard level assessments for LEO, orbital data on space debris from about 1 mm to 1 cm is required. As this need becomes more critical, the option of gathering statistical data on space debris from orbiting

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269 Wolfe, supra, note 1 at 261.

270 An earlier study indicated that, for space objects moving at 7 km/sec, IRAS could detect particles 5 cm in diameter at 3,500 km, 1 cm at 700 km, 0.5 cm at 350 km and 1 mm at 43 km. The latter measurement is somewhat approximate; R.C. Reynolds et al., "Orbiting Monitors for the Low Earth Orbit Man-Made Debris Population" in Heath, supra, note 17, 215 at 216.

271 P.D. Anz-Meador et al., "Analysis of IRAS Data for Orbital Debris" (1986), 6 Advances in Space Res 139 at 139 and SAB draft report, supra, note 3 at 16. IRAS has already shown that much more space debris exists than expected; see, infra, text accompanying note 356.

sensors will become more attractive. Ground-based radar cannot measure debris particle cross-sections, while current ground-based optical sensors have capabilities too close to threshold detection levels, have limited observation periods and are subject to atmospheric interference.[272]

Studies have shown that either an orbiting radar, lidar or optical telescope could not only detect space debris in the 1 mm to 1 cm range, but could also obtain sufficient information on object trajectories in order to discriminate between meteoroids and space debris, a critical distinction for spacecraft design considerations.[273]

A space-based radar system would require a large platform and would provide great versatility and accuracy; however, the significant power requirements may be prohibitive. Lidar systems are as flexible as radar systems and operate at shorter wavelengths than radar, thereby providing greater resolution and hence greater accuracy. A passive optical

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272 R.C. Reynolds, "Design Considerations for Orbiting Detectors for the Low-Earth Orbit Debris Population" (1985), 5 Advances in Space Res 63 at 63-64 and Sanguinet, supra, note 161 at 59. Improvements in ground-based optical devices are being studied. One system under consideration could detect an object with a 6.14 sq-cm cross-section, a capability far in excess of that now possessed by NORAD; Johnson and McKnight, supra, note 196 at 61.

273 Kessler, supra, note 3 at 60 and Reynolds, supra, note 270 at 215.

device would measure either the Sun's reflective energy off the object or the radiant energy of the object itself.[274]

The choice of which system to use is related to the number of objects which can be detected per unit of time. A passive optical system could achieve an event rate of thousands/year at 800 km for objects 10 cm in diameter or more, while lidar and radar systems will only have rates of 100/year for very small objects. Other variables to be considered are previous use, weight, accuracy and costs of construction and operation. While the passive optical device is the best overall system, it has been proposed that all three devices be flown on a dedicated platform for comparison.[275]

Microparticulate matter can also be detected in orbit. Space-based impact sensors have measured low-velocity microparticulates between 1-500 microns in size to determine

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274 Johnson and McKnight, **supra**, note 196 at 61. While radar uses reflected radio energy to detect objects, lidar (light detection and ranging) transmits optical energy at an object and measures the reflected energy on a mosaic detector; **id.**

275 Johnson and McKnight, **ibid.**, at 64. Scientists at NASA's Johnson Space Center recommended in 1984 that a dedicated space debris monitoring satellite be placed in orbit at an altitude higher than USISS in order to assess whether accumulating debris would eventually sift down to a level where a station strike would be more likely; "Station Likely to be Hit by Debris", **AvWk&SpTech** (17 September 1984) 16.

US Space Command has been requesting a deep space radar to monitor Soviet shuttle launches and provide early warning of Soviet ASAT attacks on US satellites in GEO. However, space-based radar is too costly and will remain in research and development for many years; "USSPACECOM Pushes Deep Space Radar", **Military Space** (11 May 1987) 3 and "Aldridge Says US Can't Afford SBR [Space-Based Radar]", **Military Space** (9 November 1987) 1.

whether impacts from these objects pose a danger to spacecraft after the particles separate from the spacecraft and remain in a similar orbit.[276] The device used for this measurement is a two-stage acoustic penetration and impact detector. However, a one-stage device with similar capabilities has been developed and could be considered for testing on a future space flight.[277]

(b) Facilities

At present, there is no international network for space object detection.[278] However, three organizations, two international and one national, do provide information on the number of active payloads and related objects launched. This information is helpful in ascertaining the quantity of larger space debris objects and in compiling statistical predictions therefrom.

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276 W. Frisch and E. Igenbergs, "The Contamination of Metallic Surfaces by Small Particles Impacting with Low Velocities" (1986), 6 Advances in Space Res 151 at 151.

277 U. Weishaupt and M. Rott, "Large Surface Piezoceramics Used for an Impact Detector for Micrometeoroid and Space Debris Application" (1986), 6 Advances in Space Res 155 at 155 and 158. See also, Johnson and McKnight, supra, note 196 at 64-65.

278 L. Perek, "The Environmental Impact of Space Activities" in B. Jasani (ed.), Outer Space -- A Source of Conflict. A study prepared by SIPRI and UN University (publication forthcoming) 5.

(i) International

Since 1962, the Outer Space Affairs Division of the United Nations has kept a public registry containing information on objects launched into outer space. Initially, this information was provided voluntarily to the UN Secretary-General by the launching States, pursuant to United Nations General Assembly (UNGA) Resolution 1721.[279] Since 1976, provision of certain information by the State of registry is mandatory, pursuant to the Registration Convention (articles III and V).[280] Launch announcements are published in the order they reach the United Nations, not in the time sequence of launchings.[281]

Under Article IV par 1 of the Registration Convention, the State of registry of the space object must furnish information on the name of the launching state(s); the

279 International Co-operation in the Peaceful Uses of Outer Space, UNGA Resolution 1721 (XVI) 20 December 1961. Part B, par 1 calls on "States launching objects into orbit or beyond to furnish information promptly to the Committee on the Peaceful Uses of Outer Space, through the Secretary-General, for the registration of launchings", while Part B, par 2 "[r]equests the Secretary-General to maintain a public registry of the information furnished in accordance with paragraph 1".

280 Convention on Registration of Objects Launched into Outer Space, UNGA Res. 3235 (XXIX) 12 November 1974; 1976 CanTS 36, 28 UST 695, TIAS 7762 (opened for signature 14 January 1975, entered into force 15 September 1976). For the text of the relevant portions of articles III and V, see, infra, Chapter Two: A/5, notes 165 and 194, respectively.

281 Perek, supra, note 278 at 5.

designator[282] or registration number of the space object; date and location of launch; basic orbital parameters (nodal period, inclination, apogee and perigee) and the general function of the space object.[283] This information must be provided to the UN Secretary-General "as soon as practicable" (Article IV par 1), a requirement which results in customary delays of three months to a year after launch.[284] States of registry may provide additional information about a space object from time to time (Article IV par 2), and must provide, "to the greatest extent feasible and as soon as practicable" information on previously registered objects which are "no longer in earth orbit" (Article IV par 3).[285] Thus, it is not

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282 The international designator indicates the year of the launch and the launch number within the year. Eg, 1972-58 refers to LANDSAT 1. In the United States, a capital letter designating the object type is often added. For example, 1984-90A is Ekran 13, a Soviet communications satellite, while 1984-90B signifies the rocket which launched Ekran 13. The letters C, D and E indicate space debris which followed the payload into space; Howell, supra, note 142 at 586.

283 Registration Convention, supra, note 280. For the text of Article IV, see, infra, Chapter Two: A/5, note 179.

284 A.J. Young, "Legal and Techno-political Implications of the Use of Nuclear Power Sources in Outer Space" (1987), 12 Rutgers Computer & Technol LJ 305 at 320-21. See also, A.J. Young, "A Decennial Review of the Registration Convention" (1986), 11 Annals Air & Space L 287 at 295.

285 This information is contained in UN documents prefixed with the symbol ST/SG/SER.E/____. Launchings notified to the UN by States not parties to the Registration Convention are contained in the UN documents prefixed with the symbol A/AC.105/INF.____; see UN GAOR, COPUOS, **Application of the Convention on the Registration of Objects Launched into Outer Space**, A/AC.105/382 (2 March 1987) pars 5-7 [hereafter Registration Convention Application].

mandatory either to provide information on operational debris put into space at the same time as a launch[286] or to give notice of failed launch attempts. Also, States not parties to the Registration Convention need not provide any of the required information.[287]

The non-governmental international Committee on Space Research (COSPAR)[288] established the SPACEWARN system in 1958 so that scientists around the world could have prompt access to information on new launchings and continual information on orbiting space objects.[289] Information provided by COSPAR is considered to be far superior than that available in the UN registry.[290]

COSPAR issues two publications on launch activities. The SPACEWARN Bulletin identifies active payloads according to the urgency and detail of information needed by the scientific community and, when available, provides recent international designations, texts of launching announcements, data on active

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[286] Registration Convention Application, **ibid.**, par 14. Only the United States registers operational debris.

[287] At present, China is the only launching state not a party to the Registration Convention.

[288] COSPAR is a special committee of the International Council of Scientific Unions (ICSU), a non-governmental organization composed of representatives of international scientific unions and national scientific organizations.

[289] R. Chipman (ed.), **The World in Space: A Survey of Space Activities and Issues. Prepared for UNISPACE 82** (NJ: Prentice-Hall, 1982) 656-57.

[290] Young (NPS), supra, note 284 at 321.

payloads particularly suited for international participation, and launching reports.[291] The COSPAR Information Bulletin provides a continuous record of launchings and contains more information than is required under Article IV of the Registration Convention: COSPAR designation, country of origin, launch date, lifetime or descent date, available information on the space object and its personnel (where appropriate) and the initial orbital elements of apogee, perigee, inclination and period.[292]

(ii) National

Under Article II par 1 of the Registration Convention,[293] each launching State must maintain a registry of space objects launched into Earth orbit or beyond and inform the UN Secretary-General of the establishment of this registry. The content of the registry is determined solely by the State of registry

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[291] Chipman, supra, note 289 at 658. Active payloads are identified according to a three-part classification: Category I -- spacecraft particularly suited for international participation, especially those for which prior arrangements have been circulated through COSPAR channels; Category II--space experiments of unusual general scientific interest or popular interest, and manned spaceflight and space probes not in included in Category I, and Category III -- all other space experiments, not included in either of the first two categories; id.

[292] Young (Registration Convention), supra, note 284 at 290 and 293.

[293] Supra, note 280, For the text of the relevant portions of Article II, see, infra, Chapter Two: A/5, note 163.

(Article II par 3). Thus, these registries are not consistently reliable sources of information.[294]

In the United States, responsibility for collecting information to meet this treaty obligation has been assigned to NORAD.[295] US Space Command, among other things, now monitors space activity for NORAD from the Command's Space Surveillance Center (SSC) deep inside Cheyenne Mountain in central Colorado.[296] SSC operations provide data used to compile and maintain the NORAD catalogue, to track space object re-entries and to manage collision avoidance manoeuvres.

SSC monitors every trackable orbiting object launched in the world, observing all satellite launches, breakups and re-entries, and is able to detect new launches within moments in

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[294] Information furnished by States to the Secretary-General concerning the establishment of national registries is found in UN documents prefixed by the symbol ST/SG/SER.E/INF ___; Registration Convention Application, supra, note 285, par 8.

[295] Johnson, supra, note 137 at 2-1.

[296] Howell, supra, note 142 at 584. See also, Herres, supra, note 263. In addition, the USAF Space Command was established on 1 September 1982, due to increasing military dependence on space systems, Soviet threats and far-reaching changes associated with STS orbiter operations; "USAF's Space Command to be Established Sept. 1", AvWk&SpTech (28 June 1982) 30. Command headquarters are located at Colorado Springs, CO. See also, W.B. Wirin, "United States Air Force Space Command Formed -- What It Is and How It Works" (1984), 2 Air & Space Lawyer 3.

the absence of prior notification.[297] This information is compiled in the NORAD catalogue of space objects. Although the primary function of the catalogue is to alert the NORAD commander to a decaying space object so that it will not be mistaken for a re-entering intercontinental ballistic missile,[298] it is invaluable for space debris detection, due to the capabilities of NORAD tracking devices.

However, the catalogue has its limitations. It may be significantly incomplete because only objects which have been observed by more than one radar and which could be associated with a launch are included.[299] Also, the ability to catalogue objects smaller than about 10-20 cm and above 600 km is restricted by the power and wavelength of individual radar sites and by the constraints on data transmission within the network of radar sites.[300]

SSC monitors space object breakups in order to predict the more than 500 objects which decay annually. Two weeks prior to the expected decay of any large space object, the SSC begins more frequent observations. Two hours prior to re-

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297 Howell, ibid., at 586. Initial notice for a US launch is 15 days prior to launch, while notification of most foreign launches comes from the Satellite Early Warning System; Wirin, supra, note 10 at 5. The Soviet Union does not ordinarily announce its launches in advance, nor does it announce unsuccessful launches; Howell, id.

298 Wirin, ibid., at 5. See also, infra, B/1(c).

299 Perek, supra, note 278 at 5.

300 SAB draft report, supra, note 3 at 10 and Johnson, supra, note 121 at i.

entry, a final prediction is computed, accurate to about 12 minutes. NORAD is currently working to maintain and improve its satellite-breakup reporting capability.[301]

Detection data is also used to prevent collisions between STS orbiters and catalogued pieces of space debris. During orbiter missions, information concerning possible collisions is compiled and transmitted to NASA, which assesses the collision risk and considers possible evasive action. SSC can predict the time of a debris fragment's closest approach with an orbiter, but calculation of the exact miss distance is problematic due to uncertainties in determining the relative positions of the orbiter and the debris object. Beyond warning of a close call, orbital analysts cannot predict that a collision will actually occur.[302]

(iii) Other

Other organizations also monitor space objects. However, unlike NORAD, space agencies such as NASA, ESA and the International Telecommunications Satellite Organization (INTELSAT) are concerned primarily with their own current missions.[303] NASA publishes a publicly accessible source of information, the Satellite Situation Report, which consists of data either computed at Goddard Space Flight Center or NORAD,

[301] Howell, supra, note 142 at 588 and Wolfe, supra, note 1 at 261.

[302] Howell, id.

[303] Ibid., at 584.

or provided by satellite owners. Each volume also contains the most recent Space Objects Box Score, a summary of items in the NORAD catalogue.[304] Another useful publication is provided by the Royal Aircraft Establishment. The RAE Table of Earth Satellites contains a list of space objects launched and decayed.[305]

(c) Prediction and Causal Determination

NORAD orbital data may be used to predict orbital paths, re-entry trajectories and future populations of space debris, and to determine the cause of fragmentation events.

The accurate prediction of orbital lifetimes and re-entry paths of space debris objects prior to their decay remains one of the most difficult and intractable problems of orbital mechanics. At best, it is an inexact science.[306] Lifetime estimates determine whether the orbital lifetime of a payload exceeds its active lifetime, thereby ensuring that the payload will not decay before completion of its nominal mission. Accurate calculation of the exact time and place of space object re-entry is necessary in order that adequate advance notice can be given to the situs of the re-entry.[307] In

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[304] NASA, Satellite Situation Report (30 September 1986) 1-2.

[305] Perek, supra, note 278 at 5 and n.2.

[306] NPS Working Group report, supra, note 144, pars 21-22.

[307] Janin, supra, note 222 at 34. Heavy space objects may not burn up completely during atmospheric re-entry; some pieces may hit the Earth's surface. The need for improved

addition, use of NORAD data to develop techniques for determining the evolution of space debris populations is crucial for forecasting collision risk.[308]

Determining the cause of fragmentation events is a young science. Yet this type of computer analysis has already played a pivotal role in identifying space objects which have fragmented, causes of fragmentations and, to a lesser degree, objects responsible for fragmentations.[309] Such determinations are necessary if matters of insurance, liability and responsibility are to be resolved in a just and efficient manner. Currently, the available evidence is merely speculative, due to the technical limitations of the detection equipment.[310] Until improvements are forthcoming, it will be difficult to attribute fault with the desired degree of certainty, since the very nature of circumstantial evidence requires a high standard of reliability.

The basic method for determining the cause of a fragmentation event is by backtracking orbital paths to determine

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prediction techniques has been illustrated by the re-entries of Kosmos 954 (January 1978), Skylab (July 1979) and Kosmos 1402 (February 1983); id.

308 For an example of a model for the evolution of space debris in LEO, see Reynolds, supra, note 138. This model is designed to discriminate between space objects in long-life and rapid-decay orbits and to analyse the hazard they pose to active payloads.

309 See, eg, Schefter, supra, note 121 at 51 and supra, text accompanying notes 121 and 131-133.

310 Schefter, id.

which object fragmented and the location and time of the event.[311] Since the breakup of a space object is seldom detected as it occurs, a debris cloud will be observed in the vicinity of where the object was last seen. Each piece of debris is then tracked separately; from this data, the initial position of each fragment's path can be determined. Breakup is considered to be that point where the collection of fragments have a minimum separation.[312]

Several techniques have been developed to aid in space debris analysis and causal determination.[313] One method is the Satellite Fragmentation Event (SAFE) test. SAFE combines several debris analysis methods and calculates whether a debris cloud has the characteristics of a typical collision-induced breakup or propulsion-related explosion. A high score indicates that the breakup is likely collision induced.[314]

The simulation of a space object fragmenting in orbit is a technique used to identify the original cause of the

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[311] Id.

[312] Johnson and McKnight, supra, note 196 at 58 and 60.

[313] Each of the techniques discussed, infra, was used to determine the cause of the breakup of satellite 1981-53A (Kosmos 1275). Each concluded that fragmentation was due to a collision with a piece of space debris; see McKnight, supra, note 5. See also, supra, text accompanying notes 126-127.

[314] Johnson and McKnight, supra, note 196 at 52 and McKnight, ibid., at 3. SAFE uses a checklist of criteria related to distribution of debris altitudes and fragmentation masses; see McKnight, id.

breakup.[315] The basic simulation tool is the Gabbard diagram which plots a space object's apogee and perigee heights against its orbital period. Gabbard diagrams can be used to determine whether a satellite's orbit is elliptical or circular; whether the breakup occurred at apogee, perigee or somewhere in between; whether the breakup was likely collision- or explosion-induced, and whether there are any notable characteristics which might help in the analysis.[316]

Both SAFE and simulation models are very subjective. The formulation of an objective, accurate and automated test which identifies the cause of a space fragmentation is essential to future space debris analysis. SAFE II has been developed to meet this need and is currently formulated to test whether a breakup event has been caused by a propulsion-related explosion or by a collision with a small debris fragment.[317]

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[315] Johnson and McKnight, ibid., at 60. Simulation also provides better models of the space debris environment and can account for untrackable objects in a debris cloud; id.

[316] Ibid., at 38, 41 and 45.

[317] McKnight, supra, note 5, at 1 and 5-6. SAFE II incorporates pre-breakup parameters of trackable space objects, the most important of which is the probability of collision. Other observations made before and after the breakup are used to adjust the initial probability of collision into the probability that the breakup was the result of an impact with a piece of space debris; for details, see, ibid., at 5.

D/ PROBABILITY OF THE OCCURRENCE OF A SPACE DEBRIS RISK EVENT

Calculating the probability that a space debris risk event will occur is important not only for safety considerations, but also for determining the economic and political costs of future space activities. Establishing the likelihood that a particular risk event will take place and the extent of the ensuing damage, is not yet an exact science. Several reasons for this uncertainty will be suggested. Since the risk of collision is of greatest concern to space planners at present, the probabilities of collision resulting in loss of or damage to persons and property in LEO, GEO and GTO will be discussed.

1. THE UNCERTAINTIES OF PREDICTION

The probability that a space object will collide with space debris is proportional to the density of the debris, its relative velocity at encounter, projected area of the space object and mission duration.[318] Since none of the variables used in this calculation is static, results generated from collision models are highly uncertain. For example, the concept of spatial density[319] is critical. Yet to calculate this variable, it would be necessary to detect all objects in

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318 V.A. Chobotov, "Classification of Orbits with Regard to the Collision Hazard in Space" (1983), 20 J **Spacecraft & Rockets** 484 at 484.

319 Spatial density is the average number of objects found in a unit of volume; D.J. Kessler, "Deviation of Collision Probability between Orbiting Objects: The Lifetimes of Jupiter's Outer Moons" (1981), 48 **Icarus** 39 at 39.

a specific region of outer space, an impossible task due to technological limitations[320]. Also contributing to the uncertainty of prediction are ignorance of the actual number of man-made objects in outer space, the validity of debris collision models and the future growth of space activities.

(a) Space Object Population

More than 7,000 trackable space objects now populate Earth orbit, as a result of the almost 3,000 launches by the five launch-capable nations and one international organization.[321] It is expected that by 2000 AD, this number will have increased to about 10,000.[322] As for untrackable space objects, their quantity is unknown. Best estimates indicate that there are between 10,000-15,000 objects larger than 4 cm in diameter, about 30,000 objects between 1-4 cm and anywhere

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320 See, supra, C/2(a).

321 McKnight, supra, note 5 at 1. As of 28 October 1987, there had been 2,961 launches. On that date, the Soviet Union conducted its 2,000th launch, the United States had conducted 870 launches and the rest of the world, 91 launches; "Soviets Achieve 2,000th Launch with Cosmos 1894", Satellite News (9 November 1987) 4. Although it might be concluded that with about 68 per cent of the launches, the Soviet Union is responsible for a similar proportion of space debris, the two superpowers roughly share equal responsibility for the current space debris population, since most USSR satellites have very short lifetimes; Kessler, supra, note 3 at 50.

In addition to the Soviet Union and the United States, China, Japan, India and ESA are capable of conducting launches; Kessler, ibid., at 49.

322 Howell, supra, note 142 at 588.

from 10 billion to thousands of trillions of microparticulate objects from 1-100 microns.[323]

It is estimated that the trackable space debris population is increasing at a rate of between 300-500 objects annually.[324] Future fragmentation events are expected to increase the amount of space debris in the critical, generally untrackable range of 0.1 mm to 1 cm.[325] Moreover, in comparison to the natural background particles which existed in outer space when the space age began in 1957, man-made objects have fully doubled the microparticulate population.[326]

(b) Collision Models

Observations of space object breakups indicate that the historically accepted models for predicting collisions in outer space have considerably underestimated the space debris population. This inaccuracy may be partially due to the fact that most probability models have assumed that debris objects are distributed in uniform spherical shells. However, it has

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323 Kessler, supra, note 3 at 53; Wolfe and Temple, supra, note 83 at 3, and Kessler, supra, note 82 at 587. The microparticulate population includes tiny paint flakes (trillions) and smaller dust-sized particles of aluminum oxide (tens of hundreds of trillions); Wolfe and Temple, id. Recent limited laboratory evidence suggests that the number of millimetre-sized particles is not as great as predicted in earlier calculations; Mendell and Kessler, supra, note 109 at 4.

324 Jasani, supra, note 141 at 67.

325 SAB draft report, supra, note 3 at 6.

326 Jasani, supra, note 141 at 67.

been determined that space debris is clustered in heterogeneous groups of various-sized toroids, in which the collision risk is much higher. Also, the accepted models do not account for certain preferred locations of space debris, particularly for manned operations. Therefore, spatial density charts used for these models may be biased, erring on the low side of collision probabilities and minimizing the actual hazard.[327]

(c) Future Space Activities

To forecast future space activities with some degree of accuracy, it is necessary to predict the behaviour of both natural and human forces.[328] Consequently, calculating the number, size and lifetimes of active payloads yet to be launched and determining the quantity of space debris deposited in outer space as a consequence, are fraught with uncertainty. The outline of future unmanned and manned space activities which follows should be placed in the context of this restraint.

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[327] Temple, supra, note 101 at 2-3 and 5; Wolfe and Temple, supra, note 83 at 4-5; Su, supra, note 196 at 111, and DeMeis, supra, note 19 at 11.

[328] Eg, the inability to predict increasing solar activity in 1978 brought the Skylab-1 to an untimely end; see, supra, note 223. If human behaviour were predictable, it would be easier to determine factors such as the number of explosions in orbit, the number of nations launching or having satellites launched, technical improvements leading to less frequent launches of replacement satellites, economic recessions with their accompanying financial constraints and new tracking systems to improve space debris detection abilities; Eberst, supra, note 223 at 382-83.

For telecommunication satellite activities, a lull in orders for new satellites is expected during the next few years as a result of the January 1986 Challenger disaster and other launch failures later that year. However, a vigorous recovery should occur during the next five years or so for replacement and new application satellites.[329] In the United States, much will depend on the ability to improve its launch capacity.[330] The interruption in launch services and the waiting periods for ELVs could prompt the USAF to consider in-orbit storage for its critical geosynchronous orbit spacecraft.[331] In addition, there is the possibility that hundreds of space objects may be launched into LEO if the US military Light Satellite programme begins.[332] Commercially, an innovative scheme, whereby satellite manufacturers will handle all phases of a launch, turning the payload over to the

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329 "Severe Drop in Satellite Orders Follows 1986 Launch Failures", AvWk&SpTech (8 June 1987) 19. In 1986, only 9 satellite orders were placed with manufacturers in the United States, Canada and Europe.

330 Until the United States rebuilds its launch capacity, it is without any reliable access to space. This reduced capability will result in a substantial backlog of existing and planned payloads. The demand for launch services will not be adequately satisfied by ELVs produced by the private sector for at least several years; P.M. Sterns and L.I. Tennen, "Doing Business in Space: Operating Strategies for a Changing Market" (1986), 29 Colloquium Law of Outer Space 183 at 185.

331 "USAF Weighs In-Orbit Storage of Satellites", AvWk&SpTech (7 June 1982) 19.

332 LIGHTSAT would launch light, inexpensive satellites and could become a multi-billion dollar programme; "TRW may Receive First Contract in DARPA's Light Satellite Program", Inside the Pentagon (21 August 1987) 14.

customer only after it has been delivered in orbit, may become an industry trend and speed up the recovery.[333] In addition, ESA's successful launch of its Ariane rocket in September 1987 should increase satellite launches in the near future,[334] while China has also developed satellite launch capabilities.[335]

Future manned activities will involve construction of space structures and ancillary space transportation systems. In the United States, since the Challenger accident, elimination of the STS orbiter as the focal point of the US space programme has resulted in the revival of the ELV industry.[336] With the next orbiter launch expected no earlier than September 1988,[337] and with doubts that a first flight will not

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333 See "Hughes to Sign In-Orbit Delivery Pact with British Satellite Bcstg.", Space Commerce Bulletin (5 June 1987) 2; "Hughes Selects Delta for European DBS Satellites; Will Provide Orbital Delivery", Satellite News (20 July 1987) 1, and "McDonnell Douglas Captures Third Commercial Launch Contract", Satellite News (17 August 1987) 3.

334 "Satellite Industry Breathes Easier After Successful Resumption of Ariane Launches", Telecommunication Report (21 September 1987) 53. ESA has 46 satellites waiting to be launched during the next three years; "Flight of the Ariane Shot in Arm for West", The Globe and Mail, National Edition (17 September 1987) B13.

335 "China Facility Combines Capabilities to Produce Long March Boosters, ICBMs", AvWk&SpTech (27 July 1987) 50.

336 "Shuttle Emphasis Reduced as Users Turn to Expendable Boosters", AvWk&SpTech (26 January 1987) 26. The first commercial sale of ELVs in the United States was expected in 1987; "First U.S. Commercial Sales of ELVs Expected in 1987", AvWk&SpTech (9 March 1987) 113.

337 "New Assessment Slips Shuttle Launch to September, 1988", AvWk&SpTech (13 April 1987) 28.

resume until 1989 or possibly 1990,[338] it is likely that more government, commercial, science and military users will be looking to ELV launches. This shift will increase the space debris population, since using an STS orbiter would have reduced both operational debris produced by multiple launches and fragmentation debris caused by accidental explosions of rocket bodies with unspent fuel.[339] However, the trend to ELV use could be short-lived if the proposed development of a recoverable heavy-lift vehicle (HLV) under the USAF advanced launch system (ALS) programme is successful.[340]

Plans for USISS are also uncertain. Initially, construction was expected to begin in 1993, with permanently manned operations to commence in 1995. However, under the revised USISS plan, the first station element is scheduled for launch in mid-1994, with a permanently manned capability by 1996 and a completion date of late 1998. Further slippage in orbiter

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338 "Some Officials Say Next Shuttle Launch May Not Occur Until 1990", Satellite News (3 August 1987) 8.

339 Wirin, supra, note 296 at 12. See also, supra, A/2 and A/3(a)(ii).

340 The proposed ALS, formerly known as the heavy-lift vehicle program (HLV), should be ready no later than 1998 and would be able use some of its systems for launches by 1993 or 1994; "USAF Seeks Industry Responses for Advanced Launch System", AvWk&SpTech (11 May 1987) 26. The proposed HLV system was to be developed for initial capability by 1994 or 1995; "Rockwell Predicts HLV Will Lower Launch Costs", AvWk&SpTech (2 February 1987) 24. While the proposed HLV was announced as a recoverable system, the USAF request for submission of proposals stated that "reusability of launcher systems and sub-systems should be considered".

launches and protracted negotiations of multilateral agreements could result in further delays.[341]

While US space activities are on hold, the Soviet Union has taken the lead in manned space operations. The new Mir space station (MIR) is a major step toward development of a permanent manned presence in space. In addition, the Soviet Union expects to have an orbiter ready for operational use by 1990 and is developing a second-generation MIR larger than the current facility.[342] Japan is also considering the development of a space station.[343]

Plans for other large structures will also contribute to the increase of the space debris population. These structures will be required for solar propulsion devices and solar sails; antennae, reflectors, mirrors and space telescopes; application satellites and satellite platforms; solar generators, including solar power satellites; unmanned space depots, and

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341 "NASA to Seek Design Concepts for Station Crew Escape Vehicle", AvWk&SpTech (17 August 1987) 30; "US Space Transportation System: Manifest" (1987), 3 Space Policy 159 at 161; "NASA will Proceed with Scaled-Back Space Station", AvWk&SpTech (30 March 1987) 27 at 28, and "US Partners Lurch Toward Agreement", Space Station News (26 October 1987) 2.

342 "Soviet Union Takes Lead in Manned Space Operations", AvWk&SpTech (9 March 1987) 129; "Soviets Near Flight Test of Small Manned Spaceplane", AvWk&SpTech (30 March 1987) 23, and "Mir II Appears on Soviet Horizon", Space Station News (26 October 1987) 7.

343 "Japan Sets Course for Manned Factories", Space Station News (26 October 1987) 7.

space mining and manufacturing.[344] Already, it has been announced that the first US Industrial Space Facility will be ready to launch by the end of 1990, with NASA agreeing to deliver two such facilities into orbit. ESA is also discussing plans for a polar-orbiting platform and a man-tended free-flying laboratory, while Japan is proceeding with the development of unmanned stations and manned factories.[345]

2. COLLISION PROBABILITIES

With this combination of unpredictable variables, it is not surprising that conclusions regarding the risk of collisions with space debris vary from study to study and over time. A 1982 study suggested that not only might the risk of collision become significant, but it might even preclude using certain regions of outer space in the future due to an uncontrolled growth in the amount of space debris.[346] Two years later, another study determined that although there was the potential for an increased risk of collision, current levels of space debris were not a major threat to unmanned systems and would only marginally threaten large long-duration

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[344] UN GAOR, COPUOS, Annual Report of the International Astronautical Federation on the Current State of Space Technology, A/AC.105/274 (20 June 1980) 15-25.

[345] "Manufacturing Facility in Space" (May-June 1987), Futurist 33; "Europeans Near Key Decisions on Long-Term Space Programs", AvWk&SpTech (28 September 1987) 22, and "Japan Sets Course for Manned Factories", Space Station News (26 October 1987) 7.

[346] Reynolds, supra, note 139 at 9.

manned spacecraft or high-value (ie, military) systems. That study also concluded that projected increases in space debris due solely to increased launch activity would not dramatically change its findings by 1995.[347] By 1985, it was reported that any increase in the number of large space objects would increase the risk of collision.[348] A 1987 report, based on improved modelling techniques, predicted that the probability that a space station would be struck by space debris was 1 in 10.[349]

Conclusions regarding the rate of growth of the space debris population suggest an immanent risk of collision. In 1982, it was calculated that the amount of space debris was increasing by about 13 per cent each year. At this rate, it was calculated that the space debris population would double in the next 10 years and would increase the collision hazard eight-fold in 20 years.[350] Three years later, it was stated that if past growth rates of space debris continue, collisions between objects larger than 4 cm can be expected within the next few years.[351] Moreover, recent observations indicate

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[347] Fischer and Reynolds, supra, note 212 at 401 and 406.

[348] Marshall, supra, note 7 at 424.

[349] DeMeis, supra, note 19 at 11.

[350] "The Orbiting Junkyard" (April 1982), **Futurist** 77.

[351] A typical collision would be between an old rocket body or payload and an untracked explosion fragment larger than 4 cm; D.J. Kessler, "Orbital Debris Issues" (1985), 5 **Advances in Space Res** 3 at 6. See also, Kessler, supra, note 3, for an updated version of this article.

that collisions with space debris have already occurred.[352] However, without on-site presence of sufficient duration to measure space debris and to characterize its constituent elements, the degree of increase will remain a matter of conjecture and concern.[353]

(a) In Low-Earth Orbit (LEO)

Recent research strongly indicates that previous calculations of the probability of collisions in LEO between space debris and an active payload were much too conservative. With the number of tracked space objects currently around 7,000,[354] the total space debris population in LEO has been calculated to be 8 to 11 times that amount. This quantity is much larger than was previously believed to be the case.[355] If initial

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352 See, supra, text accompanying notes 110-120.

353 Johnson, supra, note 137 at 5. Two factors contributing to the rate of increase in the space debris population are the raining of debris fragments from higher to lower altitudes where they can be tracked, and the improvement of the detection equipment itself; Johnson, supra, note 126 at 13 and Perek, supra, note 278 at 6. The discovery of this "old" debris implies that the hazard posed by space debris will not only increase in the future, but has been more serious for a longer time than previously expected.

354 McKnight, supra, note 5 at 1.

355 Taff et al., supra, note 265 at 35; Taff, supra, note 266 at 341 and 345-46, and Taff and Jonuskis, supra, note 266 at 135. The factor of 8 was from an experiment prior to the one which concluded that the factor of 11 was applicable. Moreover, all calculations, including the absolute minimum of 7,000, are conservative estimates since they are based on the assumption that all catalogued space objects were always detected by the tracking equipment and the fact that not all potentially trackable space objects can be detected at lower elevations; Taff and Jonuskis, ibid., at 135-36.

calculations derived from the first space-based observations of debris are any indication and if the results expected from improved ground-based detection capabilities are borne out, the space debris population may even be greater.[356]

Based on the number of tracked space objects in 1978, it was predicted that the first collision with space debris in LEO would occur between 1985 and 2005. The presence of untrackable space objects would have moved this date even closer.[357] More recent studies confirm that the occurrence of a collision is only a matter of time. One study suggests that if the growth of trackable space objects continues at the present rate, destruction of objects by space debris may be commonplace by the year 2000.[358] Another study concludes that if there is a steady growth of launches into LEO, space debris of 4 mm and larger will eventually become hazardous to any kind of space activity by around 2150 at the very latest.[359]

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356 Space-based calculations indicate that the number of space debris objects of about 10 cm diameter exceeds the number predicted to be observable; Anz-Meador, supra, note 271 at 139 and 142-43. As for ground-based estimates, it is expected that equipment modifications will reveal an increase in the untracked-to-catalogued ratio by a factor of two or three; Taff and Jonuskis, ibid., at 137.

357 Kessler and Cour-Palais, supra, note 7 at 715.

358 McKnight, supra, note 5 at 1.

359 Su, supra, note 196 at 109 and 114 and Mendell and Kessler, supra, note 109 at 4. This study examined the evolution of the space debris population with two different future space activities in LEO. First, the yearly traffic input of new active payloads was increased by 2, 5, 10, 20 and 50 per cent; second, in 1995, 10 large space structures of 100 metres in diameter were placed at either 500 km or 1,000 km.

The size of active payloads is a principal factor in determining future collision hazards.[360] Therefore, the collision risk is lowest to communication and other unmanned satellites. Although collisions between space debris and these active satellites were not considered to be a significant problem as late as 1984, debris particles as small as 1 mm travelling between 7-10 km/sec are now believed to pose a significant danger to active satellites.[361] The probability that there will be at least one collision between an active satellite and space debris by 1995 in the most densely populated region of LEO (900-1,000 km) is 63 per cent.[362] It has also been stated that if the satellite population continues to grow at present rates, the probability of a collision between an active satellite and space debris is a "virtual certainty".[363]

This study does not account for space debris fragments resulting from future space object breakups. If it had, the rate of space debris flux would have been accelerated at an even faster pace; Su, id.

360 Impact of Space Activities, supra, note 214, par 87.

361 Johnson, supra, note 126 at 17 and Fischer and Reynolds, supra, note 212 at 399.

362 Perek, supra, note 278 at 11 and Sehnal, supra, note 238 at 24. In 1981, it was estimated that one collision in 20 years would occur between 500 and 1,000 km and one collision in a few hundred years at 1,200 and 1,300 km; Impact of Space Activities, supra, note 214, par 85.

363 "Radioactive Space Debris Study Cites Hazards to Satellites", AvWk&SpTech (22 September 1986) 19 at 20. This statement refers to a collision with radioactive space debris; it is assumed, therefore, that a collision with any member of the space debris population is at least just as certain.

For an STS orbiter, there is a risk of collision between the orbiter and either an object which the orbiter places in orbit or an object which is already in orbit.[364] In 1982, it was estimated that the probability was a million to one that an orbiter on a four-day mission at about 270 km altitude would collide with an object larger than 1 métre.[365] In 1984, it was concluded that a one-week orbiter mission would not be threatened by space debris.[366] In 1986, it was conservatively estimated that by the year 2006 an orbiter-sized object would experience more than 10 collisions annually with space debris of 1 mm in diameter and would have a 33 per cent chance-per-year of colliding with an object 1 cm in diameter.[367] However, none of these studies predicted that an STS orbiter windshield would be damaged by a 0.2 mm particle of space debris as early as 1983.[368]

It was concluded as early as 1983 that space debris posed a severe hazard to large space systems below 1,200 km. With a

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[364] S. Footer, "Legal Issues and Answers for Commercial Users of the Space Shuttle" (1983), 13 Transportation LJ 87 at 91.

[365] Schefter, supra, note 121 at 50; see also, Chobotov, supra, note 318 at 487-88.

[366] Fischer and Reynolds, supra, note 212 at 399.

[367] SAB draft report, supra, note 3 at 4.

[368] See, supra, text accompanying notes 115-116. Based on up-to-date information on the quantity of space debris, supra, D/1(a), and improved modelling techniques, supra, C/2(c) and D/1(b), this collision event does not seem so unrealistic today.

growth rate of 5 per cent annually in large space objects, collisions were calculated to begin by about 2000; a 10 per cent annual growth rate would result in a collision by 1994. The debris fragments used in these calculations were considered to be large enough to cause extensive damage many times during the operational lifetimes of these systems.[369] A space station is a typical large structure. Different estimates are found for the probability of a collision between a space station and a tracked space debris object. One study indicates that if MIR were placed in the highest density region at 900-1,000 km, a collision would occur once in about 2,000 years. Another study suggests that at least one collision in a 100-year period is a certainty. Both studies agree that higher probabilities are more realistic for a collision between a space station and an untracked space debris object.[370]

In general, it is estimated that a space station with a cross-sectional area of 1 sq km orbiting at 500 km and an inclination of 28.5 degrees will be hit by other orbiting objects at least once a year.[371] If the station is placed at

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[369] Reynolds, supra, note 138 at 495 and Reynolds, supra, note 139 at 117. This calculation is a conservative estimate, based on the tracked space object population.

[370] Johnson, supra, note 11 at 18 and "Station Likely to be Hit by Debris", AvWk&SpTech (17 September 1984) 16.

[371] The planned orbit for USISS is 500 km altitude and 28.5 degrees inclination.

1,000 km, the probability increases to 20 times per year.[372] Another set of calculations shows that a structure of 100 m in diameter will experience 1,000 collisions annually with 1 mm particles and 25 collisions a year with 1 cm particles.[373] Neither study indicates the type of damage resulting from these collisions. Since the extent of damage will depend on where the space debris strikes and the size of the impacting object,[374] these figures should be sufficient cause for concern to NASA: USISS will have a 30-year life span.[375]

Other large structures will be similarly affected. Studies indicate that the Hubble Space Telescope will be struck by a 5 mm debris fragment during its lifetime and that there is a 1 per cent chance that it will be hit by a piece of space debris about 10 cm in diameter.[376] It has been stated that if there were 10 platforms in outer space, each 100 m across, one of them would collide with a space debris object every year.[377]

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[372] Nagatomo, supra, note 103 at 336-38.

[373] SAB draft report, supra, note 3 at 4.

[374] See, supra, text accompanying notes 207 and 100, respectively.

[375] After 30 years, USISS will be dissembled and salvaged since its technology will have become obsolete; H. DeSaussure, "The Impact of Manned Space Stations on the Law of Outer Space" (1984), 21 San Diego LR 985 at 990.

[376] "Hubble Trouble?" (January 1987), Sky & Telescope 31. See also, supra, text accompanying notes 109 and 167.

[377] Schefter, supra, note 121 at 51.

Finally, humankind itself is not exempt from the possibility of being struck by a space debris object in LEO. The probability that a piece of space debris will strike a man-sized object is low, in the order of between 1 in 1000 and 1 in 10,000. Yet it should be remembered that an object as small as a paint flake could puncture a space suit. Even if the probability of such an occurrence is more than a thousand-to-one, these odds will be small comfort to the person whose spacesuit is punctured.[378]

(b) In Geostationary Orbit (GEO)

GEO is a limited natural resource, requiring co-ordination and planning to make optimum use of its finite number of orbital positions.[379] Both the number of space objects in GEO and the probability of collisions between them are increasing.[380] Although this probability has increased as much as two orders of magnitude since 1980, the risk of collision is not serious yet.[381]

In September 1987, there were about 130 operational satellites in GEO,[382] with its active payload population

[378] Temple, supra, note 101 at 4 and DeMeis, supra, note 19 at 11.

[379] UNISPACE 82 report, supra, note 249, par 277; see also, 1983 Physical Nature report, supra, note 141, par 17.

[380] Closer Spacing report, supra, note 188, par 43.

[381] Johnson, supra, note 11 at 18 and Closer Spacing report, ibid., par 123.

[382] See, supra, note 252. See also, supra, note 251.

increasing at a rate of about 20 satellites per year.[383] The maximum number of active payloads GEO can accommodate (orbital capacity) is limited by the finite nature of GEO and the need to prevent radio frequency interference among satellites[384]. As a result, the spacing between satellites is regulated.

The primary criterion used to determine minimum spacing between active satellites is the design of Earth-station antennae; the other is station-keeping accuracy.[385] While future technological advances make it impossible to fix absolute limits on orbital capacity,[386] current levels of station-keeping technology provide satellite control to within +/- 0.1 degree (75 km). With the present regulatory régime requiring satellites to be kept within +/- 2 degrees (1,500 km) of nominal latitude and within +/- 0.1 degrees of nominal longitude, some 1,800 satellites could be accommodated without

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383 M. Hechler, "Collision Probabilities at Geosynchronous Altitudes" (1985), 5 **Advances in Space Res** 47 at 47. This study reconsiders the estimates presented by J.C. Van der Ha and M. Hechler in "The Collision Probability of Geostationary Satellites" (pre-print of paper IAF-81-332, prepared for presentation at 32nd Congress of the IAF, 1981), taking into account a larger amount of small space debris objects and thereby reflecting the actual situation after a first collision, and considers the collision risk between active payloads and longitudinally distributed inactive payloads. It should be noted that Efficient Use of GEO, **supra**, note 241, relies on the results of the 1981 study.

384 See, supra, note 245.

385 Closer Spacing report, **supra**, note 188, pars 66 and 78 and Efficient Use of GEO, **supra**, note 241, par 64.

386 W. von Kries, "Legal Status of GEO: Introductory Report" (1975), 18 **Colloquium Law of Outer Space** 31 at 32.

any risk of collision between active satellites, assuming equal demand for all segments of the GEO band. However, certain sectors of the band are used more than others, while some satellite systems need more space than others.[387]

With regard to the space debris population, it has been reported that the number of debris objects in GEO of 20 cm or more in diameter is at least 25 per cent and possibly 50 per cent that of the tracked space object population found in the NORAD catalogue.[388] With these levels of activity, the number of space objects in GEO is expected to increase by a factor of between 4 and 16 by 1995.[389]

Initially, studies evaluating risk probabilities referred to three types of collisions in GEO: collisions between two active payloads, collisions between an active payload and an inactive payload and collisions between two inactive payloads. It was not until 1984 that the probability of collisions with fragmentation debris in GEO were studied and then, only with a view to the future.[390] Collisions with microparticulate matter have not yet been considered. Superficially, the lack of data on these two classes of space debris would seem to be the best explanation for these investigative omissions. However, an equally reasonable answer may be found in con-

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[387] Ibid., at 31-32 and Wiessner, supra, note 106 at 226.

[388] Taff, supra, note 266 at 342 and 344.

[389] Fischer and Reynolds, supra, note 212 at 403.

[390] See, supra, text accompanying note 361.

siderations arising from the issue of whether the possible saturation of the orbital capacity of GEO is a physical constraint on its use[391]. The crux of this issue is the definition of orbital saturation.

GEO "would be saturated if it were impossible to place a new satellite into it without unduly increasing the probability of a collision between two satellites".[392] This definition applies only to collisions between active and inactive payloads.[393] By declining to consider the possibility of collisions between active payloads and all classes of space debris but for inactive payloads, the risk of orbital saturation is underestimated: If calculations had been made and had indicated that sufficient operational debris, fragmentation debris and microparticulate matter were present so as to pose

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391 Eg, it has been predicted that demand for satellite telecommunication services in the United States will saturate its available orbital and frequency capacity by the early to mid-1990s, even with the move to 2-degree orbital spacing; see "NASA Forecasts Satcom Capacity Saturation", AvWk&SpTech (18 April 1983) 139 and "Despite GTE Spacenet View that Emptier Arc makes Tighter Interference Rules Premature, Many Carriers, Broadcast Interests, Satellite Operators Support Proposed Rule Changes", Telecommunications Reports (15 June 1987) 13. However, the concern about orbital saturation may be short-lived if software developed by NASA lives up to its claims of being able to double or quadruple orbital capacity in GEO; "NASA Software Big Hope at Satellite Meeting, Officials Say", Space Commerce Bulletin (5 June 1987) 5.

392 1977 Physical Nature report, supra, note 219, par 21. (emphasis added)

393 Ibid., par 22. This report assumes that station-keeping manoeuvres will pre-empt collisions between active payloads (see, infra, text accompanying notes 398-400) and that collisions between inactive payloads are "irrelevant" (see, infra, text accompanying notes 411-415).

a risk of collision in a specific orbital position, a decision not to use that position in order to avoid damage to or loss of a satellite would be a constraint on the use of GEO.[394] Therefore, the extremely narrow definition of orbital saturation has biased studies toward considerations other than the possibility of collisions with those objects comprising the majority of the space debris population, thereby overlooking the possible danger they pose to active payloads.

When this definition was formulated, orbital saturation was considered to be the least severe of five constraints, "as long as small satellites were used".[395] The need to account for space debris when addressing the question of orbital saturation was made clear in 1984, when it was noted that the problem of space debris was particularly critical in GEO and that there was a "real" possibility that GEO could "become physically saturated by active payloads and orbital debris" in the future.[396] However, a 1985 study for COPUOS, while

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[394] As well, accounting for the influence of collisions between inactive payloads and other classes of space debris could result in a similar constraint.

[395] 1977 Physical Nature report, supra, note 219, par 21. Other constraints considered were saturation of the frequency spectrum for communications between a satellite and its ground station or between satellites; interruption of communications due to solar interference; cut-off of solar power, and lack of fuel for station-keeping; ibid., par 20.

[396] M.G. Wolfe et al., "Man-Made Space Debris -- Implications for the Future" in Heath, supra, note 17, 43 at 46-47. Despite this warning, at least one recent analysis of the issue declines to include the effect of the space debris population in its considerations; see Smith, supra, note 248 at 286-89 and 293.

acknowledging that the risk of collisions with space debris could constrain future use of GEO, chose not to stress this issue since the risk did "not appear to directly affect the issue of spacing between satellites[;] but further studies may be required ".[397]

The possibility of collisions between two active communication satellites was ignored when collision probabilities were first considered in 1977, since it was felt that these satellites could maintain their nominal positions through station-keeping techniques.[398] By 1980, it was recognized that there was a risk that two satellites assigned to the same nominal longitudinal position could collide, the most liberal assumptions suggesting that one collision would occur every 90 million years.[399] In 1984, this probability was still extremely low, with one collision predicted every 27,000 years.[400] However, it is significant that in four years, without accounting for untrackable space debris, the risk

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[397] Closer Spacing report, supra, note 188, par 49. With space debris populations much higher than previously expected, future studies will likely take this potentially critical limitation into consideration.

[398] 1977 Physical Nature report, supra, note 219, par 21.

[399] Efficient Use of GEO, supra, note 241, par 35; see also, Van der Ha and Hechler, supra, note 383. If 10 satellites were assigned to the same nominal longitudinal position, it was estimated there would be a collision between two of these satellites every 400,000 years.

[400] See Hechler, supra, note 383 at 49-51; Perek, supra, note 278 at 12, and Closer Spacing report, supra, note 188, par 44.

increased by a factor of a little more than 3,300. If the risk factor were to decrease by a similar amount in a similar time period, the probability of a collision in 1988 would be one approximately every 8.2 years.

The risk of collisions between active and inactive payloads is growing slowly but steadily and is directly related to the "shooting gallery" syndrome[401]. The expected time between two collisions in a sample of 100 active and 100 inactive payloads of 50 m diameter is between 400 and 700 years. At the stable points in the GEO band, the collision risk is about twice as high.[402] Another study indicates that with a sample of 100 active and 54 inactive payloads, the probability of a collision with an active payload 5 metres in diameter (the size of a typical communication satellite in GEO) is about one every 15,000 years, and with an active payload 10 m in diameter, about one every 11,000 years.[403]

The collision risk in GEO is expected to increase dramatically if large space structures are placed there.[404] As early as 1977, it was estimated that the probability of

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401 See, supra, text accompanying notes 379-383, 388-389 and 255-257. See also, Efficient Use of GEO, supra, note 241, par 36 and Hechler, ibid., at 48.

402 Perek, supra, note 278 at 12-13 and Hechler, ibid., at 56.

403 McCormick, supra, note 238 at 122.

404 1977 Physical Nature report, supra, note 219, par 26; Van der Ha and Hechler, supra, note 383 at 21, and Thomas, supra, note 251 at 307 and 313.

collision between a solar power satellite with an area of 100 sq km and a member of a population of 100 inactive payloads would be once every 5 years on average. This risk is significant since the planned lifetime of a solar power satellite is 30 years.[405] Recent calculations forecast that the probability of a collision between an active payload 100 m in diameter and an inactive payload is 1 every 120 years; if the structure is 1,000 m in diameter, the probability drops to 1 in 30 years.[406]

The effect of a large population of small debris fragments on the risk of collision in GEO was first considered in 1985.[407] The initial study concluded that small-debris populations will produce a "considerable hazard" for large structures such as antenna farms and solar power satellites.[408] As a baseline measurement, a fragmentation debris population of 0 yields a probability of 0.51 per cent that at least one collision will occur in 20 years. If there are 1,000 debris fragments, the risk climbs to a 2.1 per cent chance of collision in 20 years, and with 10,000 debris fragments, a 16 per cent chance of collision in the same

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[405] 1977 Physical Nature report, ibid., par 25.

[406] McCormick, supra, note 238 at 122.

[407] Closer Spacing report, supra, note 188, pars 46-47 and Hechler, supra, note 383 at 56-57.

[408] Hechler, ibid., at 56.

period.[409] These results indicate that the presence of a few large active payloads and a large population of small debris crossing the GEO band will prove to be "quite disastrous".[410]

Although the risk of collision between two inactive payloads was considered irrelevant in 1977,[411] it was recognized by 1980 that this type of collision was significant since it could contribute to the untrackable space debris population.[412] However, this risk was still considered to be of "no direct interest" and "no importance" in 1984, but for its contribution to the increase in small debris.[413] This conclusion ignores the fact that any increase in the total space debris population not only increases the probability of collision, but could also precipitate the cascade effect.[414] Again, recent indications of the true debris population in GEO

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409 Id. These conclusions are based on the assumption that 40, 80, 60 and 20 active payloads with cross-sections of 5, 20, 100 and 1,000 sq m, respectively, are exposed to 140, 40 and 20 space debris fragments with 5, 10 and 100 sq m cross-sections, respectively, and to an additional debris cloud of 1,000 or 10,000 pieces of 1 sq cm cross-section; id.

410 Ibid., at 57.

411 1977 Physical Nature report, supra, note 219, par 22.

412 Van der Ha and Hechler, supra, note 383 at 3 and Efficient Use of GEO, supra, note 241 at 36.

413 Kessler, supra, note 82 at 48 and Perek, supra, note 278 at 12.

414 Roth, supra, note 248 at 380.

should increase the importance of investigating this type of collision.[415]

(c) In Geosynchronous Transfer Orbit (GTO)

The chance of a collision between a spent rocket stage in GTO and an active payload in GEO has been calculated to be about two orders of magnitude less than the probability that two active payloads in GEO will strike one another. Thus, if the number of spent rockets stages is equal to the number of active payloads in GEO, the presence of this operational debris will increase the probability of collision by 1 per cent.[416]

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[415] See, supra, text accompanying notes 381-383 and 388-389.

[416] Fischer and Reynolds, supra, note 212 at 399.

CHAPTER TWO: LEGAL AND POLICY IMPLICATIONS

A/ SPACE DEBRIS AND THE INTERNATIONAL LAW OF OUTER SPACE

1. SPACE REFUSE -- A PROPOSED DEFINITION

International space law treaties contain neither a definition nor a description of space debris. In Chapter One, space debris was divided into four classes: inactive payloads, operational debris, fragmentation debris and microparticulate matter. However, opinion is divided as to whether the legal scope of space debris includes all technical categories.

"Debris" is derived from the French "débriser" which means to break down. In common English usage, "debris" means scattered fragments, wreckage or drifted accumulation.[1] Therefore, strictly speaking, space debris includes only fragmentation debris and microparticulate matter. While most legal writers acknowledge that operational debris falls within the scope of "debris", there is debate over whether inactive payloads, particularly inactive satellites, are so included. Moreover, the status of space litter is rarely discussed.

Several authors hold that inactive satellites are space debris.[2] It has also been suggested that international

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[1] The Concise Oxford Dictionary (Oxford: Clarendon Press, 1982).

[2] See, eg, I. Diederiks-Verschoor, "Legal Aspects of Environmental Protection in Outer Space Regarding Debris". Paper prepared for presentation at 30th Congress of the IISL, Brighton, 10-17 October 1987, at 4; R.C. Hall, "Comments on Salvage and Removal of Man-Made Objects From Outer Space" (1966), 9 Colloquium Law of Outer Space 117 at 119; C.Q. Christol, The Modern International Law of Outer Space (NY: Pergamon Press, 1982) 130; E.R.C. van Bogaert, Aspects of Space Law (Netherlands: Kluwer, 1980) 46 and 66; S. Gorove, "Pollution and Outer Space: A Legal Analysis and Appraisal"

organizations have adopted this definition.[3] On the facts, it is reasonable to conceptualize inactive satellites as space debris, since their uncontrolled trajectories already pose a hazard to active satellites and will increase the probability of risk events occurring in the future when larger space structures are in orbit.

Other writers exclude inactive satellites from the debris classification.[4] Arguments supporting this position are two-fold: (i) inactive satellites, particularly in GEO, are a form of use which is regulated by the ITU[5] and (ii) inactive satellites are not a form of debris contamination, since

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(1972), 5 NYU J Int'l L & Politics 53 at 56; D. Wadegaonkar, The Orbit of Space Law (London: Stevens & Sons, 1984) 55; W.B. Wirin, "The Sky is Falling[:] Managing Space Objects" (1984), 27 Colloquium Law of Outer Space 146 at 152, and F.K. Schwetje, "Space Law: Considerations for Space Planners" (1987), 12 Rutgers Computer & Technol LJ 245 at 274 and 279.

[3] I.H.Ph. Diederiks-Verschoor, "Harm Producing Events Caused by Fragments of Space Objects (Debris)" (1982), 25 Colloquium Law of Outer Space 1 at 2 and Diederiks-Verschoor, supra, note 2 at 5.

[4] See, eg, Perek, cited in Diederiks-Verschoor, supra, note 3 at 1; Finch in "Summary of Discussions" (1982), 25 Colloquium Law of Outer Space 67 at 67, and R.H. Campbell in Staff of Senate Comm. on Aeronautical and Space Sciences, 92d Cong., 2d Sess., Report on the Convention on International Liability for Damage Caused by Space Objects[:] Analysis and Background Data (Comm. Print 1972) 72.

[5] R. Müller, "The Scope of Validity and Effectiveness of Environment-Related Norms in Outer Space Law". Paper prepared for presentation at 30th Congress of the IISL, Brighton, 10-17 October 1987, at 12-13.

contamination is the introduction of foreign substances into the space environment with an intent to cause harm[6].

These contentions are not supported by the facts. The suggestion that inactive satellites are a legitimate use of GEO would be acceptable only if "use" includes "misuse". Inactive satellites only serve to increase the risk of collision in GEO and are therefore an impediment to its use. Moreover, most ITU regulations apply to space stations (transponders) on board satellites, not satellites themselves. Those provisions which do apply to satellites are generally limited to technical practices for station-keeping,[7] practices which apply only to active satellites since inactive satellites are incapable of manoeuvring.

The argument that inactive satellites do not constitute contamination and therefore are not debris, is supported by a five-part rationale: (1) "the number of items in outer space is not potentially dangerous at the moment"; (2) "technological progress will help solve the problem of removing non-operative satellites from orbit"; (3) development of international co-operation will help solve the debris problem; (4)

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[6] Y.M. Kolossov, "Legal Aspects of Outer Space Environmental Protection" (1980), 23 Colloquium Law of Outer Space 103 at 103.

[7] Eg, procedures were established at the 1977 WARC-BS for minimum spacing between active satellites using planned frequency bands; see **Final Acts: World Administrative Conference for the Planning of Broadcast-Satellite Service** (Geneva: ITU, 1977). See also, supra, Chapter One: C/1(d), note 247.

"special means" for protecting satellites from colliding with large items "may be created", and (5) meteoroid collision bumpers provide adequate "protection from collisions with small particles".[8]

This reasoning, put forward in 1980, is seriously outdated today: (1) orbital debris poses serious risks to the space environment and has already prompted debris reduction measures; (2) to date, no evidence of technically and economically feasible removal mechanisms have been developed; (3) no international co-operative measures to resolve the debris problem exist as yet; (4) the technical literature supplies no information regarding these special means;[9] and (5) meteoroid bumpers cannot adequately protect space objects from the quantity and size of debris particles now present in outer space.

The seriousness of the debris problem, the possible confusion over the literal meaning of "debris" and the need to define the scope of debris suggest the need for a legal term of art. Such a term would provide a starting point for discussing the legal issues arising from the space debris problem. The following definition is proposed and will be

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8 Kolossov, supra, note 6 at 105.

9 Although the recent discovery of Soviet ground-based lasers capable of damaging satellites could have been the "special means" to which the author alluded, this solution would create more debris of a significantly more problematic nature than it would eliminate; see "Soviet Strategic Laser Sites Imaged by French Spot Satellite", **AvWk&SpTech** (26 October 1987) 26.

used as a term of art throughout the remainder of this thesis.

"Space refuse" refers to those man-made objects in outer space deemed to be valueless, as evidenced by an absence of operational control. This definition has several advantages. First, it includes the four classes of technical space debris, thereby providing a consistency in approach. Second, it provides a value-laden orientation to the placement by man of objects in space, thereby implying that the worth of these objects is fully dependent on the actions of States.[10] Third, it is the least emotive term for describing these uncontrolled objects, merely referring to the presence of foreign objects in the outer space environment.[11] Fourth and most importantly, the idea of control over a space object as a means of ensuring that it does not become refuse has not only been advocated since the beginning of the space age,[12] but has also been

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[10] The attribution of value to those objects designated as refuse is inherent in the ordinary language definition of the term. "Refuse" is defined as "that which is cast aside as worthless" (The Oxford Dictionary, 1933, unamended by the 1982 Supplement), "that which is refused or thrown away as worthless or useless" (Webster's New Twentieth Century Dictionary of the English Language - Unabridged, 2d ed., 1975) and "that which is refused or rejected as useless or worthless" (Black's Law Dictionary, 5th ed., 1979).

[11] "Junk", "rubbish", "garbage", "waste" and "litter" have emotional overtones and could imply a moral condemnation. "Refuse" merely denotes those things which have been discarded because they are perceived as having no value.

[12] In 1958, it was proposed that "any object sent into space must be under the control of the sender so that on completing its orbital life the responsible party may guide the object back to an area safe for mankind.... No object should be placed in any orbit in outer space which cannot be guided back to earth or destroyed by some other means ....";

traditionally put forward as a means for defining inactive satellites[13]. As well, the control test provides an essential connection between the problem and any proposed remedy.

2. DO "SPACE OBJECTS" INCLUDE SPACE REFUSE?

There may be no need for an explicit definition of "space refuse", if that term is found to be subsumed under an existing space law treaty definition. The logical and reasonable concepts for this purpose would be either "contamination", found in Article IX of the Outer Space Treaty,[14] or "space object". "Contamination" may be

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A.G. Haley, "Space Age Presents Immediate Legal Problems" (1958), 1 Colloquium Law of Outer Space 5 at 6. See also, A.G. Haley, Space Law and Government (NY: Appleton Century-Crofts, 1963) 11.

In 1966, it was stated that the active lifetime of a satellite was that period during which "effective physical control is exercised over the vehicle" and included "periods of time in which a spacecraft receives and responds to commands ...[,] returns usable information to ground receiving stations" as well as "periods of planned deactivation and subsequent reactivation.... After this active lifespan is terminated (by ground command, technical malfunction, or by the breakup of the craft), a space vehicle is in a permanently inactive state, that is, its transmitters are shut down, and all equipment ceases to function. At this time there is no possibility of reactivating the craft's equipment, effective physical control ceases, and the vehicle is dead and becomes, for all intents and purposes, a large piece of debris"; Hall, supra, note 2 at 118-19 and n.12.

[13] See Diederiks-Verschoor, supra, note 3 at 2 and note 2 at 5. See also, infra, B/3(c) and (d).

[14] Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies, UNGA Res. 2222 (XXI) 19 December 1966; 610 UNTS 205, 1967 CanTS 19, 18 UST 2410, TIAS 6347 (opened for signature 27 January 1967; entered into force 10 October 1967).

eliminated, since it refers only to a limited class of fragmentation debris.[15] However, it is unclear from the legal documents, related writings and the one relevant fact situation whether "space object" includes space refuse.

(a) "Space object" in International Law

Prior to the Liability Convention[16], space objects had once been termed "artificial earth satellites and space rockets", when referring to their launching.[17] When the question arose regarding the registration of objects launched into space, States were called on to furnish information when "launching objects into orbit or beyond".[18] In the Legal Declaration,[19] a space object was referred to as "an object launched into outer space", for purposes of jurisdiction and control (Paragraph 7); as "objects launched into outer space and ... their component parts", for purposes of ownership

[15] See, infra, text accompanying notes 410-415.

[16] Convention on International Liability for Damage Caused by Space Objects, UNGA Res. 2777 (XXVI) 29 November 1971; 1975 CanTS 7, 24 UST 2389, TIAS 7762 (opened for signature 29 March 1972, entered into force 9 October 1973).

[17] International Co-operation in the Peaceful Uses of Outer Space, UNGA Res. 1472 (XIV) 12 December 1959, B, Preamble, par 1.

[18] International Co-operation in the Peaceful Uses of Outer Space, UNGA Res. 1721 (XVI) 20 December 1961, B, par 1. See also, International Co-operation in the Peaceful Uses of Outer Space, UNGA Res. 1963 (XVIII) 13 December 1963, II, par 3.

[19] Declaration of Legal Principles Governing the Activities of States in the Exploration and Use of Outer Space, UNGA Res. 1962 (XVIII) 13 December 1963.

(Paragraph 7); as "objects and component parts", for purposes of return to the State of registry (Paragraph 7), and as "object or its component parts", for purposes of liability (Paragraph 8).

The Outer Space Treaty[20] adopted the terminology of the Legal Declaration, namely "object launched into outer space" when referring to registration and jurisdiction and control (Article VIII), and object or its component parts for questions of ownership (Article VIII) and liability (Article VII). In addition, States were invited to "observe the flight of space objects launched" by other States (Article X).

In the Return and Rescue Agreement,[21] the importance of the "return of objects launched into outer space" was noted (Preamble, par 1), while notice, recovery, return and expenses incurred applied to "a space object or its component parts" (Article 5).

The Liability Convention provided the first legal description of space object, while avoiding any definition of the same. "Space object" includes a space object, the launch vehicle and the component parts of both (Article I(d)).[22] The

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[20] Supra, note 14.

[21] Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space, UNGA Res. 2345 (XXII) 19 December 1967; 672 UNTS 119, 1975 CanTS 6, 19 UST 7570, TIAS 6599 (opened for signature 22 April 1968, entered into force 3 December 1968).

[22] Article I(d) of the Liability Convention, supra, note 16, states:

For the purposes of this Convention ...

Registration Convention[23] adopted this description in its Article I(b), thereby expanding the scope of the term as used in Article VIII of the Outer Space Treaty. To date, space object has not been defined.[24]

Therefore, at international law, for purposes of liability, registration, return of objects and ownership, "space object" includes its component parts as well as the launch vehicle and its component parts. For questions of jurisdiction and control, an issue which has not been developed in any space law convention since the entry into force of Article VIII of the Outer Space Treaty, "space object" is "an object launched into outer space".

(b) Scope of "space object"

During the Liability Convention debates, it was stated that "space object" had a "reasonably understood and accepted

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(d) The term "space object" includes component parts of a space object as well as its launch vehicle and parts thereof.

23 Convention on Registration of Objects Launched into Outer Space, UNGA Res. 3235 (XXIX) 29 November 1971; 1976 CanTS 36, 28 UST 695, TIAS 7762 (opened for signature 14 January 1975, entered into force 15 September 1976).

24 US national law substitutes "space vehicle" for "space object" and defines the former as "an object intended for launch, launched or assembled in outer space, including the space shuttle and other components of a space transportation system, together with related equipment, devices, components and parts"; s. 308(f)(1) of the National Aeronautics and Space Administration Authorization Act, 1980, Pub L 96-48, 93 Stat 349 (1979).

meaning".[25] However, negotiators were not only unable to draft a definition for space object, but could not agree on a description for the term. Moreover, the question of whether space refuse is included in "space object" was never specifically addressed. The space object debate and the commentaries based on it were concerned primarily with which instrumentalities should be considered "space objects", not with the effects of these instrumentalities following their active lifetimes.

During the space object debate, it was felt that any definition of space object should encompass "all objects likely to give rise to liability",[26] since the final definition would determine to some extent the application of the Convention[27]. It was argued that "space object" should include, at the minimum, the object itself and its component parts, as well as the means of delivery and its component parts.[28] In addition, one delegation stated that "[w]hat had been generally in mind" as an appropriate definition would also include articles on board the space object and articles

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[25] UN GAOR, COPUOS, Seventh Session of the Legal Sub-Committee, A/AC.105/C.2/SR.102-110 (19 August 1968) Australia at 60. Summary Records of the One Hundred and Sixth Meeting at 55-61 contain the debate on the definition of space object and are referred to hereafter as "Space Object debate".

[26] Id.

[27] Ibid., Austria at 60.

[28] Ibid., United Kingdom at 56, Czechoslovakia at 57, Belgium at 57, Canada at 59, India at 59 and Australia at 61.

detached, thrown or launched from the space object, whether intentional or unintentional.[29] While other delegations agreed with this generalization and formulated draft definitions in accordance with it,[30] the final result reflects the narrower interpretation and avoids any reference to objects detached, launched or thrown, whether intentionally or unintentionally.

It is unclear which classes of space refuse are included implicitly in "space object", even though several authors have assumed that "space object" encompasses all space refuse,[31] a

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[29] Ibid., France at 60; see also, Italy at 56-58 and Canada at 59.

[30] Italy proposed a definition of space object which would have included "not only the launching device and the capsule, but also their component parts which become detached or are torn off during transit, and objects which have fallen or are launched from space objects", arguing that "it is necessary to assimilate to the space object its component parts and objects on board which detach themselves or are jettisoned in transit; this is for purposes of liability in the event that they cause damages"; UN GAOR, COPUOS, Report of the Legal Sub-Committee on the Work of Its Ninth Session (8 June - 3 July 1970), A/AC.105/85 (3 July 1970) Annex I at 13. Argentina, Belgium, France and Mexico agreed with this definition. Together they suggested that "space object" include the space object itself, any person on board the space object, and "any component part of a space object, parts on board, detached or torn from the space object, or the launch vehicle or parts thereof"; ibid., Annex I at 16.

[31] H. DeSaussure, "The Impact of Manned Space Stations on the Law of Outer Space" (1984), 21 San Diego LR 985 at 995 and M.J. Corrigan, "The Collision Hazard in Outer Space and the Legal System" in Space: Legal and Commercial Issues (London: Int'l Bar Assoc, 1986) 35 at 51.

point of view supported by the United States[32]. Since every object launched into space, whether or not intended for orbit, has the potential to become space refuse at some time, it is important to know exactly which of these man-made articles is included in the Article I(d) description.

Active communication satellites and spacecraft such as STS orbiters and space stations are considered to be space objects,[33] while certain types of active space instrumentalities are often excluded. Debate exists over whether "space objects" must originate on Earth;[34] whether sounding

[32] The statement that "all damage in connection with a space enterprise should be covered" by the Liability Convention implies support for the inclusion of all space refuse; Space object debate, supra, note 25, US at 56. The speaker made this point more specifically when he stated that the "fundamental purpose" of the US delegation during Liability Convention negotiations was to provide compensation for US citizens "injured as a result of the re-entry of fragments of a foreign man-made space payload or launch vehicle"; H. Reis, "Some Reflections on the Liability Convention for Outer Space" (1978), 6 J Space L 126 at 127. (emphasis added)

[33] See G.P. Sloup, "A Guide for Space Lawyers to Understanding the NASA Space Shuttle and the ESA Spacelab" (1977), 26 Zeitschrift für Luft und Weltraumrecht 197 at 199 and DeSaussure, supra, note 33 at 995, respectively. Skylab, however, would be considered a component part; see Sloup, ibid., at 206.

[34] Gorove states that origination on Earth "seems necessary if the definition [of space object] is to be in line with the space treaties currently in force", citing Article 5, par 1 of the Return and Rescue Agreement, supra, note 21. He argues that since this provision refers to a space object's return to Earth, the object must have been on Earth before it could return; S. Gorove, "Cosmos 954: Issues of Law and Policy" (1978), 6 J Space L 137 at 141, n.21. This reasoning is inconsistent with sec. 308(f)(1) of the NASA Authorization Act, 1980, supra, note 24, which states that 'space vehicle' "means an object ... assembled in outer space". It would be difficult to argue that 'space vehicle' is excluded from the

rockets are "space objects", since they do not achieve orbit,[35] and whether spacecraft which become fixed on the surface of the Moon or other celestial bodies are "space objects"[36].

The status of inactive satellites and spacecraft is uncertain, since Article I(d) gives no indication as to whether use is a criterion. It has been suggested that inactive space objects would not be included, since space objects must be "designed for use in outer space".[37]

If a functional approach is taken, all space instrumen-

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definition of space object.

[35] A memorandum submitted to the US Department of State during hearings on the Liability Convention stated that the test for space object "is not only whether the object goes into orbit or beyond, but also whether any object that is launched by rocket propulsion is intended to go into orbit or beyond"; Senate Comm. on Foreign Relations, Convention on International Liability for Damage Caused by Space Objects, S. Exec. Rep. 38, 92d Cong., 2d Sess. (1972) 9, cited in C.Q. Christol, "International Liability for Damage Caused by Space Objects" (1980), Am J Int'l L 346 at 349. See also, US Senate Report on Liability Convention, supra, note 4 at 25 and Christol, supra, note 2 at 108. Such an interpretation would exclude sounding rockets. For a contrary opinion, see N.M. Matte, Aerospace Law: From Scientific Exploration to Commercial Utilization (Toronto: Carswell, 1977) 156 and Space object debate, supra, note 25: US at 56, Belgium at 57 and France at 60. For a definition of space object which would include sounding rockets, see W.F. Foster, "The Convention on International Liability for Damage Caused by Space Objects" (1972), 10 Cndn Yrbk Int'l L 137 at 145 and n.32.

[36] See Foster, ibid., at 147 and Matte, supra, note 35 at 156-57.

[37] Gorove, supra, note 34 at 141.(emphasis added)

talities in their operational state are "space objects".[38] The definition of operational state is derived from Article VII(b) of the Liability Convention[39] and extends "from the time of [the space object's] launching or attempted launching or at any stage thereafter until its descent"[40]. Therefore, "space objects" would include all space refuse. While this definition would solve many problems, it is not entirely convincing. Not only does it clash with the ordinary language meaning of "operational state", but it also falls prey to the argument that the Article VII(b) definition is limited to specific circumstances where damage occurs to nationals of the launching State and foreign nationals participating in launch activities.[41]

(c) Scope of "component parts"

If the classes of space refuse other than inactive satellites are to be considered "space objects", they must fall under the term "component parts". However, what exactly constitutes "component parts" is not settled. While the space object debate indicates a desire by some States to develop a

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38 B. Cheng, "Convention on International Liability for Damage Caused by Space Objects" in N. Jasentuliyana and R.S.K. Lee (eds.), Manual on Space Law: Volume I (Dobbs Ferry, NY: Oceana Publications, 1979) 83 at 117.

39 For a statement of Article VII(b), see, infra, text accompanying note 228.

40 Cheng, supra, note 38 at 117.

41 Supra, note 39.

broader definition of component parts as objects intentionally or unintentionally detached, thrown or launched from a spacecraft, the decision to omit any mention of these criteria from the treaty description weakens the strength of the argument that the debate "constituted some evidence of what was meant by the terms actually used in the Convention"[42].

It was suggested during the space object debate that "all objects which were likely to give rise to liability" be included.[43] However, it is unclear whether "component parts" refers to articles carried by the space object not specifically designed to move in space.[44] For example, persons and property on board a space object are excluded in one analysis,[45] but included in another[46]. One author states that "all elements normally regarded as making up the space object ..., [that is] any object without which the spacecraft would be regarded as incomplete[,] may be taken to constitute a component part".[47] Another excludes any objects in or attached to a space object which do not "facilitate the

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42 Christol, supra, note 2 at 84.

43 Space object debate, supra, note 25, Australia at 60. See also, ibid., US at 56: "All damage in connection with a space enterprise should be covered".

44 L.P. Wilkins, "Substantive Bases for Recovery for Injuries Sustained by Private Individuals as a Result of Fallen Space Objects" (1978), 6 J Space L 161 at 162.

45 Foster, supra, note 35 at 158-59.

46 Christol, supra, note 35 at 357.

47 Diederiks-Verschoor, supra, note 2 at 3-4.

objectives of the launch" or would not be "conducive to the successful operation of the space object"[48].

From the Article I(d) definition, it is clear that all operational debris except litter is considered to be "component parts". However, recourse to the preceding comments belies this conclusion. The case for certain types of fragmentation debris and microparticulate matter is even more problematic. At best the matter is uncertain. Even if the broader interpretation is applied, only certain fragmentation debris (objects unintentionally detached) and some microparticulate matter (objects unintentionally detached)[49] qualify.

Fragmentation debris resulting from satellite breakups caused by explosions and collisions deserves special consideration, since this class of space refuse now presents the greatest risk to space objects and space activities in general. However, this hazard was not mentioned either in the space object debate or in the draft definitions for space object, nor does it fall under the broader interpretation. If a fragmentation event should occur, it is unclear whether the resulting refuse will be presumed to be a space object,[50] either as the space object itself or as a component part

[48] Christol, supra, note 35 at 357 and note 2 at 109, respectively.

[49] Paint flakes could be considered here. It would be difficult to include solid rocket motor exhaust particles or the other forms of microparticulate refuse.

[50] Wilkins, supra, note 44 at 162.

thereof. Until impact, the space object itself is not space refuse, since it can be controlled. When the object breaks up, there is no doubt that its pieces are space refuse.[51] However, it cannot be concluded with certainty that these pieces are still space objects within the scope of the Article I(d) description.[52] Also, it is unclear whether component parts include fragments of the space object itself.

(d) The Kosmos 954 Incident

The issue of whether space refuse is subsumed under "space objects" may also be examined in light of the Kosmos 954 incident, "the first instance in the history of space exploration where a claim was made by one sovereign state against another on account of damage caused by a falling space object"[53]. The fact that the USSR paid partial compensation to Canada establishes the precedential nature of the incident in the development of space law.[54]

On 4 January 1978, Kosmos 954, a 4.5-tonne Soviet ocean surveillance satellite, containing a nuclear power source fuelled by about 50 kg of uranium, burned up in the atmosphere

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[51] Diederiks-Verschoor, supra, note 2 at 5.

[52] See, eg, Summary, supra, note 4 at 67, where Okolie states that "when a space object disintegrates, it is no longer a space object, but debris".

[53] B. Schwartz and M.L. Berlin, "After the Fall: An Analysis of Canadian Legal Claims for Damage Caused by Cosmos 954" (1982), 27 McGill LJ 676 at 677.

[54] Id.

and disintegrated in the Great Slave Lake region of northern Canada.[55] The refuse was found in areas of the Northwest Territories and the provinces of Alberta and Saskatchewan; all but two pieces were radioactive, some of them lethally so.[56] The research, recovery and clean-up operation ended on 15 October 1978, costing the Government of Canada some $14 million.[57]

On 23 January 1979, Canada filed a claim against the Soviet Union for more than $6 million (Canadian) for the damage caused by Kosmos 954.[58] Canada based its claim jointly and severally on, *inter alia*, the Liability Convention.[59] A settlement was reached on 2 April 1981, with the Soviet Union agreeing to pay Canada $3 million (Canadian) "in full and final settlement of all matters connected with the disintegration" of Kosmos 954.[60]

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55 P.G. Dembling, "Cosmos 954 and the Space Treaties" (1978), 6 **J Space L** 129 at 129. Cause of the unplanned and uncontrolled re-entry is uncertain; see, **supra**, Chapter One: B, text accompanying notes 123-124.

56 "Canada: Claim Against the Union of Soviet Socialist Republics for Damage Caused by Cosmos 954" (1979), 18 **Int'l Leg Materials** 899 at 904.

57 J. Reiskind, "Towards A Responsible Use of Nuclear Power in Outer Space -- The Canadian Initiative in the United Nations" (1981), 6 **Annals Air & Space L** 461 at 463.

58 Kosmos 954 Legal Claim, **supra**, note 56 at 899.

59 **Ibid.**, at 905.

60 "Canada-Union of Soviet Socialist Republics: Protocol on Settlement of Canada's Claim for Damage Caused by 'Cosmos 954'" (1981), 20 **Int'l Leg Materials** 689 at 689.

It is clear that Kosmos 954, its nuclear reactor and component parts are "space objects" as defined by Article I(d) of the Liability Convention.[61] Therefore, by launching the claim against the USSR for damage caused by the space refuse of Kosmos 954, it can be argued that the practice of States recognizes that "space objects" includes space refuse. However, since the Soviet Union never officially admitted liability[62] and since the settlement procedures of the Liability Convention[63] were never invoked, the Convention was never applied to the issue at hand. Therefore, any interpretation derived therefrom is without legal force. Even if the Convention did apply, any space refuse which may be included under "space object" could be distinguished and limited to hazardous materials.

The Return and Rescue Agreement[64] may also provide some support for the argument that Kosmos 954 refuse constitutes a space object or portion thereof. Article 5 par 1 of the Agreement obliges a Contracting Party to notify the launching authority and the Secretary-General of the United Nations when it discovers that a space object or its component parts have

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[61] Cheng, supra, note 38 at 141.

[62] A.J. Young, "Legal and Techno-political Implications of the Use of Nuclear Power Sources in Outer Space" (1987), 12 Rutgers Computer & Technol LJ 305 at 331.

[63] Articles IX-XX of the Liability Convention, supra, note 16, provide a two-part procedure for claiming compensation. See, infra, text accompanying note 204.

[64] Supra, note 21.

come down in its territory. In the case of Kosmos 954, the Government of Canada so informed the Government of the Soviet Union.[65] The USSR acknowledged the notice. However, in the view of the Canadian government, the Soviet Union did not respond with this acknowledgement in a timely manner. As a result, the provisions of Article 5 par 2 were not invoked.[66]

Therefore, it may be concluded that the acceptance by both States that Article 5 par 1 of the Return and Rescue Agreement could apply to the facts is an implicit acknowledgement that "space object or its component parts" includes space refuse. The major problem here is that any interpretation of "space refuse" arising from the Kosmos 954 incident could be restricted to the Return and Rescue Agreement, since the definition of space object in the Liability Convention is not found in the Agreement. Also, as with the Liability Convention, this interpretation could be limited to incidents involving radioactive material, especially in light of Article 5 par 4 of the Return and Rescue Agreement which provides for material of a "deleterious or hazardous nature".

(e) Conclusion

"Space object", as found in the space treaties, does not include space refuse. Moreover, the Kosmos 954 incident

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[65] Kosmos 954 Legal Claim, supra, note 56 at 131.

[66] Article 5 par 2 of the Return and Rescue Agreement provides that, prior to recovery being undertaken by the State in whose territory the object has landed, the launching State must make a request to that State for recovery.

provides little support for the inclusion of space refuse in "space object". An obvious solution would be to amend Article I(d) of the Liability Convention and Article I(b) of the Registration Convention so as to include "space refuse" in the definition of "space object".[67] However, simply appending "space refuse" to existing treaty definitions would not cure the defect, since the scope of "space object" is by no means certain.

Accordingly, to address effectively the risks posed to space activities by space refuse, international space law requires not only a definition for space refuse, as suggested in the previous section, but also one for space object. The following definition is proposed:

"Space object" means

1/ any object
  (i) intended for launch, whether or not into orbit or beyond;
  (ii) launched, whether or not into orbit or beyond; and
  (iii) assembled in space, and
2/ any instrumentality used as a means of delivery of any object

and includes

1/ any part thereof or
2/ any object on board

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[67] See, eg, C. Fishman, "Space Salvage: A Proposed Treaty Amendment to the Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Space" (1986), 26 **Virginia J Int'l L** 965 at 988: "The term 'space object' includes space vehicles, their component parts, and any debris associated with or created by such space vehicles or their component parts". This definition has been proposed in the context of developing legal regulations for space salvage, an activity that is "often likely to involve debris"; ibid., at 991.

which becomes detached, ejected, emitted, launched or thrown, either intentionally or unintentionally, from the moment of ignition of the first-stage boosters.

3. JURISDICTION AND CONTROL OVER SPACE REFUSE

If the risks posed by space refuse are to be addressed effectively, any remedial action must consider the issue of who is vested with the right to remove space refuse. Answering this question brings into play the notions of jurisdiction and control and ownership. Article VIII of the Outer Space Treaty[68] states:

> 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 and over any personnel thereof, while in outer space or on a celestial body. Ownership of objects launched into outer space, including objects landed or constructed on a celestial body, and of their component parts is not affected by their presence in outer space or on a celestial body or by their return to earth. Such objects or component parts found beyond the limits of the State Party to the Treaty on whose registry they are carried shall be returned to that State Party, which shall, upon request, furnish identifying data prior to their return.

Article VIII raises three issues relevant to the discussion of space refuse: whether jurisdiction and control are coextensive, whether space refuse is within the scope of Article VIII and whether jurisdiction and control over space objects is permanent.

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68 Supra, note 14.

(a) Coextensivity

If jurisdiction and control are coextensive, then only one legal test will be necessary for determining when space objects can be removed from their orbits. The positions of the two major space powers on this issue are contained in the negotiating documents of the Outer Space Treaty and commentaries based on the Treaty itself. The United States believes the terms are coextensive; the Soviet Union believes they are not.

The United States used the expression "jurisdiction over a space vehicle" in its early draft proposal for what would become Article VIII.[69] Later, Article VIII adopted substantially the same wording as that of Principle 7 of the Legal Declaration.[70] With regard to the latter, it was suggested that the phrase "jurisdiction and control" "apparently refers to legal control rather than physical control over orbiting

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[69] UN GAOR, United States of America: Draft Declaration of Principles Relating to the Exploration and Use of Outer Space, A/C.1/881 (14 October 1962) Principle 7.

[70] Principle 7 of the Legal Declaration, supra, note 19, states:

> The State on whose registry an object launched into outer space is carried shall retain jurisdiction and control over such object, and any personnel thereon, while in outer space. Ownership of objects launched into outer space, and of their component parts, is not affected by their passage through outer space or by their return to the earth. Such objects or component parts found beyond the limits of the State of registry shall be returned to that State, which shall furnish identifying data upon request prior to return.

unmanned space vehicles".[71] Since Principle 7 and Article VIII are so similar, there is no reason why this interpretation cannot apply to "jurisdiction and control" in Article VIII as well. The documented US position on Article VIII is that "a nation which constructs and orbits a spacecraft, manned or unmanned, retains ownership and control over the vehicle no matter where it is located".[72]

The US interpretation reflects the view of British and North American common law traditions, where jurisdiction "is an aspect of sovereignty and refers to judicial, legislative, and administrative competence", and encompasses the powers to make decisions or rules (prescriptive jurisdiction) and to enforce them (prerogative jurisdiction).[73]

The Soviet Union assigns different meanings to "jurisdiction" and "control". Unlike the US proposal, the USSR draft of Article VIII includes both terms: The State of registration is said to "retain jurisdiction and control over" space

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[71] Hall, supra, note 2 at n.12.

[72] Staff of the Senate Comm. on Aeronautical and Space Sciences, 90th Cong., 1st Sess., **Report on Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies[:] Analysis and Background Data** (Comm. Print 1967) 30-31.

[73] I. Brownlie, **Principles of Public International Law**, 3d ed. (Oxford: Clarendon Press, 1979) 298. Space law has abandoned the use of nationality and territory to signify attribution of jurisdiction over space objects. A substantial connection with the State of registration is invoked as a substitute; ibid., at 421 and 428.

objects.[74] Jurisdiction refers to the legislative, executive and juridical power of the State of registration, while control refers to "activities of special services of the registering state aimed at monitoring the technical condition of the space object", navigating the space object and guiding the activities of its crew.[75]

The distinction between the two positions lies in the removal by the USSR of administrative functions from the jurisdictional umbrella and placing them in a separate category. The legal effect of this separation is negligible, since both the United States and the Soviet Union recognize in fact that physical control functions are within the scope of Article VIII.

(b) Scope

The principle of jurisdiction and control is of no relevance for remedial action, if space refuse is not within the scope of Article VIII. The only class of space refuse specifically acknowledged as falling under this provision is inactive satellites, as neither the United States nor the

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[74] UN GAOR, Draft Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, the Moon and Other Celestial Bodies, A/6352 (USSR, 16 June 1966) Article V.

[75] V.D. Bordunov, "Rights of States as Regards Outer Space Objects" (1981), 24 Colloquium Law of Outer Space 89 at 90-91.

Soviet Union distinguishes between active and inactive satellites for purposes of jurisdiction and control.[76]

To determine which space objects are space refuse, the test of "effective physical control"[77] could be established as a means for distinguishing active satellites from inactive ones. This test would not only conform with both the US and Soviet interpretations of jurisdiction and control, but would also determine when State jurisdiction and control over space objects ends.

Successful application of the effective physical control test is hampered by several obstacles. First, jurisdiction and control of a State over its space objects is considered to be permanent.[78] Second, the validity of the test would depend on whether "space objects" include "space refuse",[79] a question which must be answered in the negative[80]. Third, even if "space refuse" is subsumed under "space object", this definition is valid only under the Liability Convention and cannot refer back to a previous treaty.[81]

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[76] Hall, supra, note 2 at 118 and Kolossov, **supra**, note 6 at 105.

[77] Hall, ibid., n.12. See also, **supra**, **text accompanying** notes 12-13.

[78] See, infra, A/3(c).

[79] Summary, supra, note 4 at 67.

[80] See, supra, A/2(e).

[81] See articles 28 and 31(1) of the **Vienna Convention on the Law** Treaties, UN GAOR, A/CONF.39/11/Add.2 (opened for signature 23 May 1969, entered into force 27 January 1980).

(c) Permanency

On the question of whether jurisdiction and control over space objects is permanent or whether it may lapse in certain circumstances, legal opinion favours permanency.[82] In the space refuse context, however, this position is weakened by the following considerations: (1) permanent jurisdiction and control impedes attempts to minimize the quantity of space refuse,[83] since owners may not care what happens to their space objects after their useful lives have ended[84]; (2) most discussions of jurisdiction and control are concerned only with dangers posed by inactive satellites to space navigation,[85] thereby ignoring the three other classes of space refuse; and (3) permanent jurisdiction and control applies

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Article 28 states that treaty provisions are not retroactive unless so intended; Article 31(1) states that treaty terms are to be interpreted according to the context in which they are found and with regard to the purpose of the treaty.

[82] See, eg, Hall, supra, note 2 at 118; Diederiks-Verschoor, supra, note 2 at 2; E. Gordon, "Toward International Control of the Problem of Space Debris" (1982), 25 Colloquium Law of Outer Space 63 at 64; A.J. Young, Space Transportation Systems (Montreal: McGill University, 1984) 295; Schwetje, supra, note 2 at 280; Müller, supra, note 5 at 12, and J.J. Foley and R.F. Scoular, "'Made in Space' -- International Legal Aspects of Manufacturing in Outer Space" in Space: Legal and Commercial Issues, supra, note 31, 105 at 133.

[83] Gordon, supra, note 82 at 64.

[84] Diederiks-Verschoor, supra, note 3 at 2.

[85] See, eg, Hall, supra, note 2; Schwetje, supra, note 2 at 278-79 and 280-83, and Young, supra, note 82 at 294-97.

only to identifiable space objects,[86] to the exclusion of the untrackable ones. As previous critiques have not addressed the entire spectrum of space refuse when considering the legal effects of Article VIII, it is possible that States would be willing to cede jurisdiction and control in certain circumstances.

Ownership of space objects is also permanent, as Article VIII implies that the State of registration may not be divested of title to its space objects,[87] regardless of the use or condition of the space object[88]. Moreover, the rights of ownership include the rights of possession, use and disposal, thereby denying a right of encroachment without the consent of the State of registration.[89]

The question then arises as to whether there are any exceptions to the absolute nature of jurisdiction and control and ownership for the purposes of removing or otherwise disposing of space refuse. Under sentence 3 of Article VIII,[90] the duty of States parties to the Outer Space Treaty to return space objects found outside the territory of the

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86 Hall, ibid., at 121.

87 D.M. Wanland, "Hazards to Navigation in Outer Space: Legal Remedies and Salvage Law", at 30. Research prepared for the NASA-AMES/University Consortium for Astrolaw Research, Hastings College of Law, University of California, and published in (1985), 1 J Astrolaw 1.

88 Gordon, supra, note 82 at 64.

89 Bordunov, supra, note 75 at 91.

90 See, supra, text accompanying note 68.

State of registration suggests a starting point for considering removal of space refuse. However, reading this provision together with Article 5 par 1 of the Return and Rescue Agreement[91] demonstrates that sentence 3 of Article VIII is intended to refer only to those space objects and their component parts which have returned to Earth.[92] Two other possible sources for exceptions are the analogy with abandonment from maritime law and sentence 1 of Article IX of the Outer Space Treaty.

In maritime law, abandonment arises where no personnel remain on board a vessel and there is no intent to return and reactivate it. At such a time, the object becomes a derelict and is subject to salvage.[93] In space law, a derelict space object would be

> one which is abandoned and deserted by those who were in charge of it, without hope on their part of recovering it and without intention of returning to it. Thus, manned spacecraft, abandoned by the crew without intention of returning to or recovering it, would be derelict. Unmanned satellites and other objects with an 'active lifespan' would be considered derelict when this active lifespan is terminated, that is, in a permanent inactive state ....[94]

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91 Supra, note 21.

92 L. Perek, "Telecommunication and the Geostationary Orbit: The Missing Regulation" (1983), 26 Colloquium Law of Outer Space 33 at 35 and Young, supra, note 82 at 296-97.

93 Hall, supra, note 2 at 117 and 119. For application of maritime salvage law to space law, see Wanland, supra, note 87 at 17-31; Young, ibid., at 286-300, and Fishman, supra, note 67.

94 Wanland, ibid., at 29.

The test for this "permanent inactive state" could be "effective physical control".[95]

But is the hazard posed by space refuse to space activities sufficient justification for its unauthorized and possibly unilateral removal? It has been argued that removal of space refuse would be permitted only with the consent of the State of registration since (1) any unilateral action violates the provisions of Article VIII;[96] (2) unauthorized removal becomes trespass, international theft and piracy, or an unwarranted act of aggression, depending on the circumstances;[97] and (3) authority to remove "identifiable" space refuse is vested in the State of registration in times of peace and in absence of an international treaty to the contrary[98].

On the other hand, consent of the State of registration may be unnecessary if (1) the possibility exists that persons or property of innocent third-party States may be injured, lost or damaged;[99] (2) the hazard threatens the safety of spaceflight;[100] or (3) a satellite begins to fall from orbit

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[95] Supra, text accompanying note 77.

[96] Kolossov, supra, note 6 at 105.

[97] Hall, supra, note 2 at 121.

[98] Id.

[99] Fishman, supra, note 67 at 95.

[100] H. DeSaussure, "The Application of Maritime Salvage to the Law of Outer Space" (1985), 28 Colloquium Law of Outer Space 127 at 131. If such a threat exists to the orbital path

and poses an immanent threat of serious harm to Earth[101]. While these arguments could provide the basis for a strong exception to the absolute jurisdiction and control and ownership of the State of registration, only the first applies to all classes of space refuse.

Sentence 1 of Article IX of the Outer Space Treaty states:

> "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, including the moon and other celestial bodies, with due regard to the corresponding interests of all other States Parties to the Treaty.[102]

It has been suggested that the obligations to co-operate, provide mutual assistance and have due regard for the corresponding interests of other States limit the absolute nature

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or trajectory of space objects, removal of the hazardous space object would be subject to rules of public international law. If no such threat exists and removal is based on the economic value of the space object, then any such removal would be governed by rules of private international law; id. However, rules for either contingency do not yet exist.

101 H. DeSaussure, "An International Right to Reorbit Earth Threatening Satellites" (1978), 3 Annals Air & Space L 383 at 391-92. In this case, a State other than the State of registration has a unilateral humanitarian right of protective jurisdiction to recover or otherwise remove a threatening satellite, with the minimum possible control over the space object, subject to notice to the State of registration, consultation with that State prior to removal, and independent verification; id.

102 Supra, note 14. For a detailed analysis of Article IX, see, infra, B/1(a).

of the provisions in Article VIII.[103] Accordingly, the wilful failure to remove a hazardous space object might be considered contrary to the corresponding interests of other space nations.[104]

Application of sentence 1 of Article IX must be tempered by two considerations. First, the Outer Space Treaty provides for competing interests. The freedom to use outer space for space activities[105] acknowledges the right of States to use outer space for orbiting satellites and for navigation. It might also be in the interest of launching States to leave inactive satellites in orbit if it would be too expensive to remove them. On the other hand, this freedom must be balanced against the rights of spacefaring nations to safe navigation. It is in their interests to have outer space free from navigational hazards.[106] However, space law provides no rules for designating the priority of these competing interests. Second, it has been argued that the corresponding interests of States are limited to harmful contamination, adverse changes to the environment of Earth and potentially harmful inter-

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[103] DeSaussure, supra, note 101 at 90.

[104] Wanland, supra, note 87 at 8.

[105] Article I of the Outer Space Treaty, supra, note 14, states in part:

> Outer space, including the moon and other celestial bodies, shall be free for exploration and use by all States without discrimination of any kind, on a basis of equality and in accordance with international law ....

[106] Wanland, supra, note 87 at 8-9.

ference. This limitation is said to exclude threats posed by space refuse.[107]

(d) Conclusion

Since Article VIII provides the only substantial outer space law treaty references to jurisdiction and control and ownership,[108] clarification of the nature, extent and manner of any interference with these rights will be necessary.[109] These issues must be resolved to avoid international friction[110] or the possibility of international incidents triggered by unauthorized removal,[111] especially where preventative measures for removal are not perceived to be in the common interests of all nations[112].

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107 See, infra, text accompanying notes 355-357.

108 Article II par 2 of the Registration Convention, supra, note 23, provides for the joint registration of objects, "without prejudice to appropriate agreements concluded or to be concluded among the launching states on jurisdiction and control over the space object and over any personnel thereof". Article 12 par 1 of the Agreement Governing the Activities of States on the Moon and Other Celestial Bodies (Moon Agreement), UN GAOR, A/RES/34/68 (5 December 1979); opened for signature 18 December 1979, entered into force 11 July 1984, provides for jurisdiction and control over persons and property on the Moon and for ownership of property on the Moon. Neither provision alters the substance of Article VIII.

109 C.W. Jenks, Space Law (London: Stevens & Sons, 1965) 238. Jenks suggests that only the most "extraordinary emergency would justify interference" with Article VIII rights; ibid., at 239.

110 Hall, supra, note 2 at 119.

111 Ibid., at 122.

112 See DeSaussure, supra, note 101 at 193.

It has been suggested that if a State of registration does not remove a hazardous space object within a reasonable time period and does not consent to removal by another State or entity, then if that space object causes damage, (1) the State of registration should be absolutely liable for damage caused by that space object or (2) some form of the **res ipsa loquitur** doctrine should be invoked, attributing **prima facie** negligence to the State of registration.[113] It has also been proposed that the State of registration should be considered negligent for wilful failure to remove an inactive space object, if appropriate removal technology exists.[114]

These remedial attempts are commendable. However, they refer at best to inactive satellites and other identifiable space refuse only. These remedies suggest no means by which hazardous space objects can be removed and damage prevented, but only offer compensation after the fact. Moreover, application of the **res ipsa loquitur** and negligence doctrines requires a duty of care which has yet to be clarified.[115]

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[113] Hall, **supra**, note 2 at 122. The **res ipsa loquitur** doctrine may be invoked where (i) a plaintiff cannot establish the exact cause of an accident; (ii) the accident is of a kind which does not ordinarily happen without negligence; (iii) a duty of care owed to the plaintiff has been breached; (iv) the defendant breached that duty and is therefore negligent; (v) the defendant's negligence caused the accident, and (vi) the accident caused damage; J.G. Fleming, **The Law of Torts**, 6th ed. (Australia: Law Book Co., 1983) 288-89. For more details, see, **ibid.**, 288-99.

[114] Young, **supra**, note 82 at 299.

[115] See, **infra**, text accompanying notes 251-255.

Finally, the res ipsa loquitur doctrine will be difficult to apply since it requires that the defendant have exclusive control over the inactive space object.[116] However, this control is vested in the plaintiff State of registration.[117]

Therefore, the present international legal régime authorizes no exceptions to the provisions of Article VIII, which would allow for the removal of space refuse by any entity other than the State of registration. Moreover, any remedies suggested for future implementation do not apply to the entire spectrum of space refuse. Furthermore, prior to any consideration of the issues posed by Article VIII, legal definitions of space refuse and space object will be necessary.

4. INTERNATIONAL RESPONSIBILITY FOR SPACE REFUSE

There have been no international initiatives to date mounted to combat the space refuse problem. The question therefore arises whether the doctrine of international responsibility may be invoked to ensure that States and international organizations will be obliged to remove the space refuse which they have created already and will continue to generate in the future. To answer this question, the doctrine of international responsibility as it exists in public international law and space law will be discussed. In

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[116] Hall, supra, note 2 at 112, n.32.

[117] Supra, text accompanying notes 82-89.

addition, a severe restriction on the application of the principle of international responsibility to the problem of space refuse will be noted and a viable remedy proposed.

(a) Public International Law

Since principles of international law apply to space law,[118] the doctrine of international responsibility in public international law must be considered. Generally, for international responsibility to arise there must be, inter alia, the breach of a legal obligation.[119] This principle applies to treaty law, customary international law and general principles of international law.[120]

In international law, legal obligations are created by rules and regulations. Therefore, in the absence of rules or regulations either prohibiting or regulating specific acts or omissions, there can be no attribution of international responsibility. In addition, any regulatory régime establishing legal obligations must be as specific as possible, since

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[118] Article III of the Outer Space Treaty, supra, note 14, states in part:

> States Parties to the Treaty shall carry on activities in the exploration and use of outer space, including the moon and other celestial bodies, in accordance with international law, including the Charter of the United Nations....

[119] Brownlie, supra, note 73 at 435. "[T]he major issue in a given situation is whether there has been a breach of duty ..."; ibid., at 434. See also, M. Lachs, **The Law of Outer Space: An Experience in Contemporary Law-Making** (Netherlands: Sijthoff Leiden, 1972) 124.

[120] K. Wiewiorowska, "Some Problems of State Responsibility in Outer Space Law" (1979-80), 7 J Space L 23 at 30.

legal issues in international law rely heavily on the individuality of the case.[121]

An exception to the general principle of international responsibility, which has evolved gradually and has been applied only in exceptional cases,[122] is the doctrine of abuse of rights. This doctrine states that compensation for damage may arise as a consequence of acts which are not unlawful.[123] Such a rule is necessary in certain situations, since to deny responsibility, even when there is "no omission of duty, no fault, no violation of a specific rule of law, would not only be inequitable, but would defeat the very purpose of the law".[124]

The doctrine of abuse of rights is applied mostly to risks connected with hazardous or ultrahazardous activities arising from the application of modern technology,[125] and has been accepted in space law in the form of absolute liability for damage caused by space objects on the surface of Earth or

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121 Brownlie, supra, note 73 at 441.

122 Lachs, supra, note 119 at 124.

123 Brownlie, supra, note 73 at 443.

124 Lachs, supra, note 119 at 124.

125 See Wiewiorowska, supra, note 120 at 32 and A. Kiss, "The International Protection of the Environment" in MacDonald, R.St.J. and D.M. Johnson (eds.), **The Structure and Process of International Law** (Netherlands: Nijhoff, 1986) 1069 at 1076.

to aircraft in flight[126]. Application of the abuse of rights doctrine is limited, however. While it is "useful as an agent in the progressive development of the law", it "does not exist in positive law as a general principle".[127]

An important application of the general principle of international responsibility is found in the relatively new field of international environmental law. In this field, international responsibility for protection of the environment has been established as a basic principle. As space refuse is a major issue when considering protection of the outer space environment,[128] a brief review of the evolution of this principle in the environmental context will prove instructive.

The link between international responsibility and environmental concerns can be traced to the Roman principle, sic utere tuo ut alienum non laedas (use your property so as not to injure your neighbour). In modern times, this "good neighbour" principle has been restated in the Corfu Channel case[129] which arose after two British warships were damaged by mines in the territorial sea of Albania. Albania was held

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126 See Lachs, supra, note 119 at 125 and Wiewiorowska, supra, note 120 at 32. Article II of the Liability Convention, supra, note 16, provides for this liability.

127 Brownlie, supra, note 73 at 445. See also, Wiewiorowska, ibid., at 32 and Kiss, supra, note 125 at 1076.

128 See, eg, Diederiks-Verschoor, supra, note 3 at 1; Gorove, supra, note 2 at 54-56, and Christol, supra, note 2 at 131.

129 United Kingdom v. Albania (Corfu Channel - Merits), [1949] ICJ Rep. 4.

responsible under international law, since every State has an "obligation not to allow knowingly its territory to be used contrary to the rights of others".[130]

On the facts, Corfu Channel is limited to cases where the damage and the act causing the damage both occur in the territory of the State responsible for that act. The Trail Smelter arbitration[131] extends the duty to avoid contrary use of State territory to the territory of States other than the one in which the act causing the damage originates. The arbitration tribunal, in ruling that Canada must pay compensation to the United States for damage caused by a Canadian manufacturer to property in US territory, held that States have a duty to avoid acts in their territory which cause damage in the territories of other States. These decisions support the view that international responsibility for environmental protection is limited to those territories under State jurisdiction.

The scope of international responsibility was expanded further by Principle 21 of the 1972 Stockholm Declaration on the Human Environment[132]. Principle 21 states:

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[130] Ibid., at 22.

[131] United States v. Canada (Trail Smelter Arbitration) (1931-41), 3 RIAA 1905.

[132] Declaration of the United Nations Conference on the Human Environment. The official text of this declaration is contained in Report of the UN Conference on the Human Environment, UN Doc A/CONF.48/14 (1972) 2-65 and Corr.1 (1972).

> States have, in accordance with the Charter of the United Nations and the principles of international law, the sovereign right to exploit their own resources pursuant to their own environmental policies, and the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction. (emphasis added)

Principle 21 has been accepted as a rule of customary international law[133] and is viewed "as 'laying down the basic rules governing' the international responsibility of states concerning the preservation and protection of the environment"[134]. Consequently, every State is responsible for ensuring that its activities do not cause damage to the environment outside that State -- including outer space[135]. Despite the acceptance of Principle 21 by the international community,[136] unanimity of agreement on its construction is lacking[137].

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[133] Kiss, supra, note 125 at 1074-1075 and Christol, supra, note 35 at 353.

[134] Christol, id.

[135] Kiss, supra, note 125 at 1085.

[136] This principle was confirmed and its legal significance acknowledged by UNGA Res. 2995 (XVII) 15 December 1972; Christol, supra, note 35 at 353 and n.24.

[137] J. Bruhács, "Some Remarks on the International Legal Order Relating to the Protection of Environment in Space Law". Paper prepared for presentation at 30th Congress of the IISL, Brighton, 10-17 October 1987, at 3. Issues of interpretation include whether Principle 21 is a new rule of law or merely the juxtaposition of two old ones; whether it brings about strict liability, and whether a violation of the principle is an illegal act or merely the breach of a moral attitude; id.

(b) Space Law

In space law, the basic statement of international responsibility is found in Article VI of the Outer Space Treaty[138]. Sentence 1 of that article states:

> States Parties to the Treaty shall bear international responsibility for national activities in outer space, including the moon and other celestial bodies, whether such activities are carried on by governmental agencies or by non-governmental entities, and for assuring that national activities are carried out in conformity with the provisions set forth in the present Treaty.

That acceptance of this principle was accompanied by no acrimonious debate[139] is likely the result of two factors: (1) the provision did not "involve any new or inherently unacceptable principle for States which ... envisage[d] playing an important part in space activities"[140] and (2) sentence 1 of Article VI is substantially a repetition of sentence 1 of Principle 5 of the Legal Declaration[141]. The principle of international responsibility is also found, but in a more

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138 Supra, note 14.

139 P.G. Dembling, "Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space Including the Moon and Other Celestial Bodies" in **Manual on Space Law: Volume I**, supra, note 38, 1 at 17.

140 Jenks, supra, note 109 at 211.

141 Supra, note 19. Sentence 1 of Principle 5 of the Legal Declaration states:

> States bear international responsibility for national activities in outer space, whether carried on by governmental agencies or by non-governmental entities, and for assuring that national activities are carried on in conformity with the principles set forth in the present Declaration.

specific context, in Article 14(1) of the Moon Agreement, where it applies to "national activities on the moon" rather than "national activities in outer space, including the moon and other celestial bodies".[142]

Inclusion of international responsibility as a general principle of space law ensures that international organizations and non-governmental entities fall under the umbrella of space law.[143] States are not only responsible for their space activities, but also for ensuring that these activities conform with treaty provisions.[144] Sentence 1 of Article VI is also intended to ensure that any space activity, no matter who conducts it, is carried out according to the rules of international law; to bring any consequences arising from any space activity within the jurisdiction of the State undertaking the activity, and to "remove all doubts concerning imputability".[145] In addition, States cannot devolve their Article VI responsibility.[146]

(c) A Severe Restriction and its Remedy

It would appear that Article VI of the Outer Space Treaty and Principle 21 of the Stockholm Declaration are applicable

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142 Moon Agreement, supra, note 108.

143 Dembling, supra, note 139 at 17.

144 US Senate Report on the Outer Space Treaty, supra, note 72 at 27-28.

145 Lachs, supra, note 119 at 122.

146 Jenks, supra, note 109 at 211.

to the question of space refuse, thereby making States responsible for damage caused by space refuse in the outer space environment. However, neither Article VI nor Principle 21 authorizes the establishment of the specific regulatory régime necessary for attribution of the international responsibility for which they provide. Effective control of the proliferation of space refuse will be provided in space law only through the adoption of "specific and sufficiently detailed standards of conduct".[147] In addition, the doctrine of abuse of rights is of no force, since it does not have the support at international law to be invoked in a general manner and focuses on compensation for, not prevention of, damage.

But there is a more fundamental reason why Article VI and Principle 21 cannot be relied on for resolving the space refuse dilemma. The very legal structure of the international community severely restricts the application of the principle of international responsibility contained in these provisions.

Traditionally, international law has been based on the concept of State sovereignty.[148] Although there is a growing interdependence among States arising from the need for co-operation, States act selfishly in pursuit of their own interests. As a result, the international community is not a

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147 P.M. Sterns and L.I. Tennen, "Principles of Environmental Protection in the Corpus Juris Spatialis". Paper prepared for presentation at 30th Congress of the IISL, Brighton, 10-17 October 1987, at 5-6.

148 Kiss, supra, note 125 at 1071.

cohesive legal entity.[149] Rather, each State thinks of itself as a separate and independent legal unit. Accordingly, when States consider the consequences of their acts, they are more likely to think of the effect these acts have on individual States, not on the world community of nations as a whole.

This situation extends into the realm of space activities.[150] From the outset of the space age, "the most compelling component of space activity has been nationalism, not planetary responsibility".[151] The lack of a cohesive or global approach assumes a special importance in matters involving protection of the outer space environment, of which space refuse is a particular instance.

Outer space is a global commons, a vast territory shared by all nations. At law, its use and exploration is "for the benefit and in the interests of all countries".[152] Since environmental protection in outer space transcends national boundaries,[153] the traditional approach can "never ensure ...

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[149] B. Bakotic, "Space Law Problems at the Turn of the Century: An Overview of Some Warning Trends in Public International Law" (1983), 26 Colloquium Law of Outer Space 343 at 344.

[150] Id.

[151] Gordon, supra, note 82 at 63.

[152] Article I of the Outer Space Treaty, supra, note 14, states in part:

> The exploration and use of outer space, including the moon and other celestial bodies, shall be carried out for the benefit and in the interests of all countries, irrespective of their degree of economic or scientific development, and shall be the province of all mankind.

[153] Sterns and Tennen, supra, note 147 at 5.

protection ... of the outer space from pollution"[154]. Problems arising in a global commons require global solutions which, in turn, call for different, more general approaches.[155] One such approach would view the legal obligations flowing from the principle of international responsibility as a commitment to protect the interests of Earth ~~and out~~er space, as well as the interests of individual nation States.

As the most recently explored global commons, outer space can provide mankind with an opportunity to develop universal approaches to problem solving. Any sound solutions derived from these approaches will include the assumption that the interests of the entire international community take precedence over the interests of its individual member States. The Stockholm Conference demonstrates that such an assumption is workable and can bear valuable fruit. The Declaration developed by that conference was "the first acknowledgement by the community of nations that new principles of behavior and responsibility must govern their relationship in the environmental era".[156]

There is no reason in principle why the space nations and those international organizations using and exploring outer

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[154] Kiss, supra, note 125 at 1080.

[155] Id.

[156] L.B. Sohn, "The Stockholm Declaration on the Human Environment" (1973), 74 Harvard Int'l LJ 423 at 432.

space cannot put aside the traditional structure of national self-interest and adopt a globally responsible approach, if not for all space activities, then at least for developing a system of international rules to provide for the attribution of international responsibility for the creation of space refuse. In this way, all States would share responsibility for protection of the outer space environment and would at the same time protect the interests of all States undertaking space activities.

5. IDENTIFICATION OF SPACE REFUSE

If space refuse is to be removed from outer space or if States liable for damage caused by their space refuse are to be held accountable for their actions, there must be a means for identifying the State responsible for the refuse. The extent to which provisions are made in space law for the identification of space refuse is determined by the extent to which identification of space objects is provided for under the Registration Convention.

(a) The Need for Identification

The importance of "precise physical identification" of space objects has been recognized since the earliest days of the space age.[157] A well-designed system of registration may

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[157] M. McDougal et al., Law and Public Order in Outer Space (New Haven: Yale University Press, 1963) 569.

provide for identification of space objects[158] and for attribution of nationality. The latter is required for purposes of jurisdiction, international responsibility, return of fallen space objects and liability[159] and for preventing collisions between space objects[160]. Identification of space objects makes possible the attribution of nationality. As well, it provides a means for determining the quantity of space refuse in orbit in order to set safety standards and to devise methods of eliminating it.[161]

The Registration Convention was drafted in order to provide for attribution of nationality and identification of space objects.[162] In reality, however, it addresses only the former function. Under Article II par 1 of the Registration Convention, each launching State must maintain a registry of

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158 P.G. Dembling and S.S. Kalsi, "Pollution of Man's Last Frontier: Adequacy of Present Space Environmental Law in Preserving the Resource of Outer Space" (1973), 20 Netherlands Int'l LJ 125 at 142.

159 A.A. Cocca, "Convention on Registration of Objects Launched into Outer Space" in **Manual on Space Law: Volume I**, **supra**, note 38, 173 at 179-80. For additional reasons for registering space objects, see C.S. Sheldon II and B.M. DeVoe, "United Nations Registry of Space Vehicles" (1970), 13 **Colloquium Law of Outer Space** 127 at 129-30.

160 I.I. Kotlyarov, "Space Monitoring Facilities and Environmental Protection" (1982), 25 **Colloquium Law of Outer Space** 5 at 6.

161 Staff of Senate Comm. on Aeronautical and Space Sciences, 94th Cong., 1st Sess., **Report on the Convention on Registration of Objects Launched into Outer Space: Analysis and Background Data** (Comm. Print 1975) 4.

162 See Preamble, pars 2-4 and 7 of the Registration Convention, **supra**, note 23.

space objects launched into Earth orbit or beyond and must inform the Secretary-General of the United Nations of the establishment of this registry, the content of which is determined solely by the State of registry (Article II par 3).[163] The national register "confers nationality for purposes of jurisdiction"[164] only. The United Nations operates a compulsory system for the registration of space objects, pursuant to Article III of the Registration Convention.[165] Content of the UN Register, prescribed by Article IV par 1 of the Convention,[166] is mandatory. The function of the UN Register is limited to "facilitat[ing] operation of existing treaties".[167]

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163 Article II, pars 1 and 3 of the Registration Convention, ibid., state:

> 1. When 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 which it shall maintain. Each launching State shall inform the Secretary-General of the United Nations of the establishment of such a registry.
> 3. The contents of each registry and the conditions under which it is maintained shall be determined by the State of registry concerned.

164 A.J. Young, "A Decennial Review of the Registration Convention" (1986), 11 Annals Air & Space L 287 at 298.

165 Article III par 1 of the Registration Convention, supra, note 23, states:

> The Secretary-General of the United Nations shall maintain a Register in which the information furnished in accordance with Article IV shall be recorded.

166 For the text of Article IV, see, infra, note 179.

167 Young, supra, note 164 at 298.

Identification of space objects involves two phases: detection and identification.[168] The Registration Convention contains no provisions for detection, relying on the facilities of States and international organizations.[169] The identification phase could prove "invaluable, perhaps even indispensible, in determining the state bearing responsibility for injury or damage caused by space objects".[170] Yet the role of the United Nations in this matter is minimal and beyond the scope of the Registration Convention, as evidenced, for example, by its ineffectiveness in the identification of Kosmos 954.[171] In addition to accomplishing little toward the establishment of a system which positively identifies space objects, the information which the Convention does require cannot be used by international organizations to correlate observations of space objects.[172] As a result, identification will often depend on the willingness of the State most likely to face liability to co-operate in the process of identification.[173]

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168 McDougal et al., supra, note 157 at 569.

169 See, supra, Chapter One: C/2(b).

170 I.A. Vlasic, "Disarmament Decade, Outer Space and International Law" (1981), 26 McGill LJ 135 at 190.

171 Young, supra, note 164 at 295, 296 and 300.

172 Schwetje, supra, note 2 at 262.

173 Gordon, supra, note 82 at 64.

(b) Limitations of the Registration Convention

There are several reasons for the ineffectiveness of the Registration Convention in providing for identification. A major obstacle is the Convention's scope. Registration is necessary only for "space objects" (Article I(b)). However, it is unclear which objects launched into space, other than active satellites and any trackable, operational debris accompanying them, are included in this definition.[174] For example, since no specific provision is made for inactive satellites, only the United States has consistently registered them.[175] Moreover, "as is clear from Article IV", identification of space objects is "principally oriented to the regulation of satellites with fixed orbital parameters"; therefore, the need to register space objects in varying orbits "may prove problematic".[176] Also, on a strict reading, objects constructed entirely from space resources could be excluded from the Register.[177]

Article II par 1, which further delimits the scope of the Convention, states that only "objects launched into earth

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174 Supra, text accompanying notes 33-52. Cf, Christol, supra, note 2 at 145, where it is stated that the Registration Convention is "properly associated with fragments of space objects". No direct support is given for this proposition, however.

175 Cocca, supra, note 159 at 180.

176 P.D. Nesgos, "The Space Station: Legal Implications" in Space: Commercial and Legal Implications, supra, note 31, 79 at 83.

177 Id.

orbit or beyond" must be registered. This provision has been interpreted so as to exclude unsuccessful launches, launches of sub-orbital sounding rockets or ballistic missile test vehicles, types of fuels or exhausts, chemical or radioactive payloads and any other thing which may "actually or potentially affect the space environment".[178]

Second, the identification function of the Registration Convention is without force due to the paucity of information required under its Article IV[179]. While the goals of the Convention included prompt reporting and standardization of

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[178] N. Jasentuliyana, "Environmental Impact of Space Activities: An International Law Perspective" (1984), 27 Colloquium Law of Outer Space 390 at 395. See also, Cocca, supra, note 159 at 181 and US Senate Report on Registration Convention, supra, note 161 at 13.

[179] Article IV of the Registration Convention, supra, note 23, states:

1. Each State of registry shall furnish to the Secretary-General of the United Nations as soon as practicable, the following information concerning each space object carried on its registry:
(a) Name of launching State or States;
(b) An appropriate designator of the space object or its registration number;
(c) Date and territory or location of launch;
(d) Basic orbital parameters, including:
(i) Nodal period,
(ii) Inclination,
(iii) Apogee,
(iv) Perigee;
(e) General function of space object.
2. Each State of registry may, from time to time, provide the Secretary-General of the United Nations with additional information concerning a space object carried on its registry.
3. Each State of registry shall notify the Secretary-General of the United Nations, to the greatest extent feasible and as soon as practicable, of space objects concerning which it has previously transmitted information, and which have been but are no longer in earth orbit.

the data base for improved monitoring space objects,[180] the requirements of paragraph 1 of Article IV have been described as insufficient even for avoiding collisions between two trackable, active space objects, and as "useless" for assessing the space refuse problem.[181] Specifically, this provision fails to provide for information on the orientation of orbit;[182] data on the position of the satellite, either in its initial or current orbit;[183] notice of impending re-entry;[184] notice of space object breakup, with accompanying parameters of each breakup fragment,[185] and notice of change in orbit subsequent to launch, due either to intentional manoeuvres or to the effects of physical perturbations[186].

Although this type of information would assist in the identification of space objects, provision of "additional information" is discretionary (Article IV par 2). Lack of a

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180 US Senate Report on Registration Convention, supra, note 161 at 12.

181 R.T. Swenson, "Pollution of the Extraterrestrial Environment" (1985), 25 Air Force LR 70 at 81.

182 Id.

183 P.Q. Collins and T.W. Williams, "Towards Traffic Systems for Near-Earth Space" (1986), 29 Colloquium Law of Outer Space 161 at 168.

184 Schwetje, supra, note 2 at 262. This notice is important since re-entering space objects spin and tumble when they start to decay; consequently, their orbits change quicker than those of more stable space objects; id.

185 Swenson, supra, note 181 at 81.

186 Sheldon and DeVoe, supra, note 159 at 139.

mandatory régime for such information has been described as "most regrettable"; without it, no improvement has been made to the voluntary nature of the registration system in effect prior to the entry into force of the Registration Convention on 15 September 1976.[187] Furthermore, the inadequacies of Article IV are acknowledged in the treaty itself by Article VI.[188] Instead of relying on the UN Register, States requir-

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[187] Cocca, supra, note 159 at 182. In US Senate Report on Registration Convention, supra, note 161 at 21-23, it has been recommended that provision of the following information "would be helpful" in "ensuring maximum benefits from the registration system": (1) registration every 30 days and within 60 days from launch or first discovery; (2) registration of all active satellites and operational debris; (3) notice of significant changes in orbital elements resulting from manoeuvres and perturbations, such changes to be reported every 30 days and within 60 days of discovery; (4) shape, dimension, weight of space objects, along with model and lifting capacity of their launch vehicles; (5) exact time and location of launch; (6) notice of intermediate orbital elements until final registered orbit attained; (7) notice of all "disappearances from sustained flight of space objects", including the reason (collision, natural decay, planned re-entry), whether the object or any part thereof was discovered and exact location of discovery; (8) notice of failed launch attempts, including information required for (4), (5) and (7); (9) notice of all registrations and reports of space flights predating the Registration Convention; (10) more explicit information on the function of space objects, and (11) radio frequencies on which signals are sent from spacecraft.

For an enumeration of information required by the COSPAR SPACEWARN system for launching announcements and orbital elements, see, ibid., at 3.

[188] Swenson, supra, note 181 at 81. Sentence 1 of Article VI of the Registration Convention, supra, note 23, states:

> Where the application of the provisions of this Convention has not enabled a State Party to identify a space object which has caused damage to it or to any of its natural or juridical persons, or which may be of a hazardous or deleterious nature, other States Parties, including in particular States possessing space monitoring and tracking facilities, shall respond to the greatest extent feasible to a request by that State

ing additional information for identifying space objects must turn to the information banks of other States parties.

Third, Article IV par 1 disregards the need for timeliness in reporting information, when it states that information shall be furnished "as soon as practicable". This requirement does not imply that information must be conveyed in advance, but only when it is feasible to do so.[189] Therefore, this provision results "invariably in ex post facto notification".[190] Moreover, most information is outmoded before it is reported,[191] since it may take weeks or even months to furnish the required data[192]. This lack of timeliness is critical, since such lengthy delays could defeat the purpose of not only the Registration Convention, but also the Liability Convention.[193]

Finally, under Article V of the Registration Convention, compulsory markings are not required; however, if markings are

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Party, or transmitted through the Secretary-General on its behalf, for assistance under equitable and reasonable conditions in the identification of the object.

189 US Senate Report on Registration Convention, supra, note 161 at 12-13.

190 Young, supra, note 82 at 282.

191 Swenson, supra, note 181 at 81.

192 Vlasic, supra, note 170 at 190. As of 1985, the average delay was about four months. The shortest delay was 26 days, while the longest was 11 months; Young, supra, note 164 at 295.

193 US Senate Report on Registration Convention, supra, note 161 at 13.

used, they must be registered.[194] Therefore, the most obvious and convenient method for identifying space objects is voluntary.[195] If markings were mandatory, they would facilitate both the identification of the State of registry[196] and the future management of space traffic[197]. Noting that the provision of markings is within the realm of current technology, it has been proposed that a category of identifying marks be added to the registration system.[198]

Four possible types of markings were put forward in 1970 by the Scientific and Technical Sub-Committee of COPUOS during

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194 Article V of the Registration Convention, supra, note 23, states:

> Whenever a space object launched into earth orbit or beyond is marked with the designator or registration number referred to in article IV, paragraph 1(b), or both, the State of registry shall notify the Secretary-General of this fact when submitting the information regarding the space object in accordance with article IV. In such case, the Secretary-General of the United Nations shall record this notification in the Register.

195 Whether markings should be mandatory or discretionary was the most debated legal issue arising from considerations of the Registration Convention in the Legal Sub-Committee of COPUOS; Cocca, supra, note 159 at 184. The United States "consistently and continuously opposed" mandatory markings, the rationale being two-fold; markings would not survive re-entry, and the necessary technology to provide such markings would be unacceptably expensive; see Matte, supra, note 35 at 182 and US Senate Report on Registration Convention, supra, note 161 at 13.

196 Vlasic, supra, note 170 at 190.

197 Young, supra, note 164 at 296.

198 Young, supra, note 82 at 298.

during its study of registration and identification issues.[199] The alternatives were (1) special markings such as metal plates (and, today, name marks); (2) detailed descriptions of the structure of space objects and the materials and components used; (3) registration of transmitter frequencies, and (4) information on flight trajectories.[200] Perhaps the most interesting suggestion concerned the reference under alternative (2) to the then "possible future developments in the use of non-harmful radioactive tracer elements [for] application to identification". If technically possible and economically reasonable, this type of marking would go a long way to solving the identification problem, especially for space refuse fragments resulting from object breakup, microparticulate matter and untrackable operational debris.

(c) Conclusion

The Registration Convention does little to either identify or aid in the identification of space refuse. Since the Convention does not make satisfactory provision for the identification of space objects, it can be of no use for identifying space refuse, most notably in its untrackable manifestations. Especially critical is the uncertainty of the meaning of "space objects", a term which at best includes the

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[199] UN GAOR, COPUOS, **Report of the Scientific and Technical Sub-Committee on the Work of its Seventh Session**, A/AC.105/82 (1 May 1970) pars 39-43.

[200] **Ibid.**, par 41.

majority of active space objects and operational debris, although the scope of the latter remains unclear. Even if this problem of terminology were resolved, remaining obstacles would include the lack of mandatory provisions for detection; the insufficiency of data necessary for timely, reliable and accurate identification of "space objects", and the failure to provide for a mandatory marking scheme.

6. COMPENSATION FOR DAMAGE CAUSED BY SPACE REFUSE

Compensation for damage caused by space refuse in outer space will never be an adequate substitute for preventing the generation of space refuse. However, some legal mechanism is necessary in order that claimant States, private owners and insurers are able to recover any losses which do occur. In space law, this function is the reserve of the Liability Convention.[201]

Under the Liability Convention régime, States are absolutely liable for damage caused by their space objects on the surface of Earth or to aircraft in flight (Article II)[202] and are subject to fault-based liability for damage caused in outer space (ie, other than on the surface of Earth or to aircraft in flight) by their space objects to space objects of other States (Article III)[203]. If damage caused in outer

[201] Supra, note 16.

[202] For the text of Article II, see, infra, note 264.

[203] Article III is discussed, infra, at A/6(b).

space results in damage to a third-party State on the surface of Earth or to its aircraft in flight, the absolute liability of first two States is joint and several (Article IV par 1(a)). If damage caused in outer space results in damage to the space object of a third-party State in outer space, the liability of the first two States is joint and several, in proportion to the fault of each (Article IV par 1(b)).

Settlement of claims for compensation is governed by a two-part procedure.[204] Diplomatic channels are used initially (Article IX). Failing resolution of the dispute after one year from the date of notice of submission of the claim documentation, a Claims Commission is established to decide the issue on its merits (Article XIV). The compensation which the launching State is liable to pay is based on the principle of **restitutio in integrum**, ie, the amount which will restore the injured party "to the condition which would have existed if the damage had not occurred" (Article XII).

Two significant facts should be noted at the outset. First, negotiations for the Liability Convention were triggered by concerns over the possible harm to persons and property on Earth resulting from the atmospheric re-entry and return to Earth of space objects.[205] From the US perspective, for example, the fundamental purpose of the negotiations was

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204 For all elements of the procedure for settlement of disputes, see articles VIII-XX of the Liability Convention, supra, note 16.

205 Cheng, supra, note 38 at 83-84.

to provide compensation for damage arising from these harms.[206] Second, in order to ensure that a treaty satisfactory to all parties would be drafted, negotiators in the Legal Sub-Committee of COPUOS did not address several questions thought to be "relatively exotic" at the time.[207] One such question was the risks posed by space refuse.[208] As a result, the Liability Convention does not "meaningfully" address the issue of damage to persons or property in outer space, although Sub-Committee members recognized that the need for such a treaty would arise when the presence of humans in outer space became more "frequent and numerous".[209]

With these limitations in mind, two issues of substantive importance to the space refuse question will be discussed: the meaning of "damage" and "space object", and fault-based liability for damage in outer space.

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206 Reis, supra, note 32 at 127.

207 Id.

208 Even up until the time the Liability Convention entered into force on 1 September 1972, there was very little knowledge about space refuse. At that time, questions raised by the existence of space refuse and its potential hazards were in the earliest stages of scientific investigation. In fact, the first major conference to address the space refuse issue was not convened until 1982. The proceedings of this NASA conference are published in D.J. Kessler and S-Y Su (eds.), Orbital Debris. Proceedings of a Workshop sponsored by the NASA Lyndon B. Johnson Space Center, Houston, Texas, 27-29 July 1982 (Washington, DC: NASA Scientific and Technical Information Branch, 1985).

209 Reis, supra, note 32 at 127.

(a) The Meaning of "damage" and "space object"

Article I(a) of the Liability Convention states:

> The term "damage" means 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 intergovernmental organizations.[210]

While damage to persons and property in outer space is included in this provision, it is generally agreed that damage to the outer space environment per se is not within the scope of the Convention[211]. Since no compensation is available for environmental damage, launching States are not liable for the mere presence in outer space of space refuse such as microparticulate matter and very small pieces of fragmentation debris. Therefore, launching States have no legal incentive to avoid the generation of this space refuse.

A strong argument for amending the Liability Convention so as to include damage to the outer space environment per se

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210 Supra, note 16.

211 See, eg, Jasentuliyana, supra, note 178 at 395; Swenson, supra, note 181 at 79; A. McCloud, "Space Pollution". Paper prepared for presentation at 30th Congress of the IISL, Brighton, 10-17 October 1987, at 2; S. Ospina, "Outer Space: 'Common Heritage' or 'Common Junkyard' of Mankind?" Paper prepared for presentation at 30th Congress of the IISL, Brighton, 10-17 October 1987, at 1-2; H. Qizhi, "Towards International Control of Environmental Hazards of Space Activities". Paper prepared for presentation at 30th Congress of the IISL, Brighton, 10-17 October 1987, at 2; I.I. Kushkuvelis, "Functional Approach and Beyond: Towards A Functional Aerospace Environmental Regime". Paper prepared for presentation at 30th Congress of the IISL, Brighton, 10-17 October 1987, at 3, and I.H.Ph. Diederiks-Verschoor, "The Legal Aspects of Space Activities with Potentially Harmful Effects on the Earth and Space Environments" (1972), 15 **Colloquium Law of Outer Space** 268 at 273.

is based on the fact that outer space is a global commons, similar to Antarctica and the high seas.[212] Even if this amendment were enacted, resolution of three legal issues would still remain outstanding: legal standing for claimant States (who is going to speak for mankind?), assessment of damages[213] and nature of the liability.

As outer space is one of the global commons of mankind, it could be argued that each State speaks for its citizens and therefore for that segment of mankind under its jurisdiction. Accordingly, each State would exercise an ecological right to ensure the preservation of outer space for future generations.[214] Assessment could be based on the principle of restitutio in integrum,[215] in order to cover the cost of

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212 Jasentuliyana, **supra**, note 178 at 295 and Swenson, **supra**, note 181 at 79. See also, Kiss, **supra**, note 125 at 1083-1087.

213 Diederiks-Verschoor, **supra**, note 211 at 273.

214 As noted in McCloud, **supra**, note 211 at 2, assigning each State a property interest in outer space would run afoul of the non-appropriation principle, found in Article II of the Outer Space Treaty, **supra**, note 14, which states:

> Outer space, including the moon and other celestial bodies, is not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means.

For a discussion of the possibility of establishing "private" property rights in GEO as a policy tool for reducing the risks posed by space refuse, see D.A. Olmstead, "Orbital Debris Management: International Co-operation for a Growing Safety Hazard" in G.W. Heath (ed.), **Space Safety and Rescue 1982-83. Proceedings of the 15th and 16th International Symposia on Space Safety and Rescue, held in conjunction with the 33rd and 34th International Astronautical Congresses** (San Diego, CA: Univelt, 1984) 241.

215 See Brownlie, **supra**, note 73 at 457-64.

returning the environment to its state prior to the damage. Although it has been proposed that a launching State should be absolutely liable for any damage it causes to the outer space environment per se, identification of the liable State would be extremely difficult, especially if the damage is caused by smaller space refuse objects.[216]

The Liability Convention provides the most current description of a "space object". Its Article I(d) states:

> The term "space object" includes component parts of a space object as well as its launch vehicle and parts thereof.[217]

However, this description is riddled with uncertainties and ambiguities.[218] To reiterate, the only space refuse within the scope of "space object" with any degree of certainty is operational debris, to the exclusion of inactive satellites, fragmentation debris, microparticulate matter and litter.[219]

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216 Jasentuliyana, supra, note 178 at 395. On the difficulties associated with identification, see, supra, Chapter One: C/2. On the basis for liability in outer space, see, infra, A/6(b).

217 Supra, note 16.

218 For an analysis of "space object", see, supra, A/2.

219 Support for this proposition is found in Swenson, supra, note 181 at 80: "The original satellite being left in space after it became nonfunctional was not an occasion for liability; neither was its breakup into many smaller pieces"; and in Kushkuvelis, supra, note 211 at 3: "It is doubtful whether [the Liability Convention] covers damages[sic] from space debris .... [T]he problem of when a space object becomes debris is left open."

(b) Fault-based Liability

Even if, for the sake of argument, it is assumed, that all classes of space refuse fall within the scope of "space object", the principle of fault-based liability is a further impediment in the quest for compensation for damage caused by space refuse in outer space. Article III of the Liability Convention states:

> In the event of damage being caused elsewhere than on the surface of the earth to a space object of one launching State or to persons or property on board such a space object by a space object of another launching State, the latter shall be liable only if the damage is due to its fault or the fault of persons for whom it is responsible.[220]

The application of this provision to space refuse is doubtful, since Article III "appears to be primarily concerned with a possible collision between [active] space objects"[221]. Consequently, the risks posed by space refuse,[222] including that of collision between an active space object and any item of space refuse, were not foremost in the minds of the

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220 Supra, note 16.

221 US Senate Report on Liability Convention, supra, note 4 at 27.

222 The risks posed by space refuse include collision, which may result in total loss of property or life, damage to persons or property, generation of further space refuse, misinterpretation, release of contamination, or the need to alter space operations or space object design; interference due to the quantity of space refuse accumulating in outer space, and use of space refuse for military purposes; see, supra, Chapter One: B.

Article's negotiators.[223] However, even if damage caused by space refuse were within the ambit of Article III, issues which would remain unresolved include foreseeability of damage, the scope of eligible claimants, the elements of fault and application of the rationale for fault-based liability to damage caused by space refuse.[224]

(i) Foreseeability of Damage

Article III does not specify whether the damage caused must be reasonably foreseeable. It has been stated that only a causal connection between the accident and the damage need be established, thereby "leaving a broad discretion so that each claim can be determined on its merits and in light of justice and equity, for it is difficult, if not impossible to foresee all the circumstances that may result in damage".[225] This interpretation is essential in order to ensure that a

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[223] This oversight is apparent in discussions of Article III in the literature, which generally assume that the major cause of damage in outer space will be collisions between two active space objects.

[224] For comprehensive historical analyses of all legal issues arising from Article III, see the relevant sections of Foster, supra, note 35; Cheng, supra, note 38, and Matte, supra, note 35; for contemporary analyses of these issues, see Christol, supra, note 35, M.S. Firestone, "Problems in the Resolution of Disputes Concerning Damage Caused in Outer Space" (1985), 59 Tulane LR 747 and K.D. Heard, "Space Debris and Liability: An Overview" (1986), 17 Cumberland LR 167. See also, Reis, supra, note 32.

[225] Foster, supra, note 35 at 158. See also, Senate Comm. on Foreign Relations, Convention on International Liability for Damage Caused by Space Objects, S. Exec. Rep. 38, 92d Cong., 2d Sess. (1972) 362.

launching State will be held liable for damage caused by space refuse. It is difficult to ascertain what damage will result, for example, from a collision between a breakup fragment and an active satellite, or to predict when the particular form of damage will occur. Possible damage could include material damage to the satellite, interruption of ground reception of the signals from the satellite, interference with signals from other satellites and interference with scientific experiments.

(ii) Scope of Eligible Claimants

The language of Article III of the Liability Convention, Article VII of the Convention and the inter-party waiver of liability found in US National Air and Space Administration (NASA) launch agreements place restrictions on who may seek compensation for damage caused by space refuse in outer space.

Article III states that the damage must be caused by "a space object of another launching State"(emphasis added). Therefore, if two space objects, each owned by a different private entity, collide and if both entities are under the jurisdiction of the same launching State, compensation for any damage resulting from that collision is unavailable.[226] The same result would follow if one of the space objects were a piece of identifiable space refuse.

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226 S.C. Kenney, "The Impact of Product Liability Law on Commercial Activities in Space" in Space: Legal and Commercial Issues, supra, note 31, 209 at 233.

Also, consider the situation where an astronaut or cosmonaut undertaking an EVA is killed when a piece of hardware (say, a bolt), negligently released during a previous mission, punctures his spacesuit. Under Article III, a claim by the estate of the deceased is excluded, since persons or property must be "on board" a space object in order to recover damages.[227]

Article VII of the Liability Convention states:

> The provisions of this Convention shall not apply to damage caused by a space object of a launching State to:
> (a) Nationals of that launching State;
> (b) Foreign nationals during such time as they are participating in the operation of that space object from the time of its launching or at any stage thereafter until its descent, or during such time as they are in the immediate vicinity of a planned launching or a recovery area as a result of an invitation by that launching State.[228]

Therefore, nationals of the launching State cannot seek compensation under the Liability Convention, whether they are on Earth or in space. They do have recourse, however, under national law.[229] In addition, claims of foreign nationals are

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[227] Cheng, supra, note 38 at 14. This claim would also be excluded under Article VII of the Liability Convention; see, infra, text accompanying notes 228-231.

[228] Supra, note 16.

[229] For US national law on space liability, see two articles by J.A. Bosco: "Practical Analysis of International Third Party Liability for Outer Space Activities -- A US Perspective" (1985), 29 Trial Lawyer Guide 298 and "Liability of the US Government for Outer Space Activities Which Result in Damages, Injuries or Death" (1986), 51 J Air L & Comm 809.

eliminated if these persons are participating in any phase of a space activity, whether as employee or invitee.

The exclusion of claims by nationals has an ancillary, yet substantive, effect on the scope of eligible claimants, when the definition of launching State is considered. It is possible that for every space object launched there could be four "launching States": State A procures a launch which is carried out by State B using the facilities of State C in the territory of State D.[230] Therefore, nationals of all these States would have no remedy under the Liability Convention. Moreover, if any of these States had entered into a joint venture with another State, the number of excluded State nationals would increase.[231]

The spectrum of eligible claimants is further delimited by certain allocation of risk provisions found in the NASA Launch Agreement[232]. Originated by NASA, this approach has

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[230] Article I(c) of the Liability Convention, supra, note 16, states:

The term "launching State" means:
(i) A State which launches or procures the launching of a space object;
(ii) A State from whose territory or facility a space object is launched[.]

[231] Article V par 1 of the Liability Convention, supra, note 16, provides for joint and several liability when two States undertake a joint launching venture. Therefore, both States are launching States for the purpose of Article VII(a).

[232] Launch Agreement (sample): Agreement Between the United States of America by the National Aeronautics and Space Administration and Satellite Business Systems for Launch and Associated Services, Launch Agreement No. 1009-001, effective date: 17 June 1980, in S. Gorove (ed.), United States Space Law: National and International Regulation (Dobbs Ferry, NY:

been adopted by Arianespace for its launch services and is found in various articles of memoranda of understanding relating to USISS.[233] Therefore, the liability provisions contained in the Agreement could become a space law precedent for determining eligible claimants.

Under the NASA Launch Agreement, both NASA and the user agree to a no-fault, no-subrogation, inter-party waiver of liability.[234] This provision obliges "each party ... to be responsible for any damage it sustains to its own property and employees involved in shuttle operations".[235] The inter-party waiver extends to third parties, their property and employees,

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Oceana Publications, 1982) I.A.7. Part I, Article V of the Agreement is entitled Allocation of Certain Risks.

233 Nesgos, supra, note 176 at 87.

234 Article V, s. 3(a) of the NASA Launch Agreement, supra, note 232, states in part:

> To simplify the allocation of risks among NASA and all users of the Space Transportation System and to make the use of the Space Transportation System feasible for the use and exploration of outer space by all potential users, the parties agree to a no-fault, no-subrogation inter-party waiver of liability under which each party agrees to be responsible for any Damage which it sustains as a result of Damage to its own property and employees involved in STS Operations during such operations, which damage is caused by NASA, the User or other users involved in such STS Operations during such operations, whether such Damage arises through negligence or otherwise.... It is the intent of the parties that this inter-party waiver of liability be construed broadly to achieve the intended objectives.

235 R.A. Tepfer, "Allocation of Tort Liability Risks in the Space Shuttle Program" (1983), Air Force LR 208 at 209. (emphasis added)

and includes "the contractors and sub-contractors at every tier of both parties and other shuttle users".[236]

Consequently, the Launch Agreement excludes all suits brought against NASA for damage resulting from collisions with or interference caused by space refuse, even if the identity of the launching State creating the space refuse can be ascertained and the fault of the launching State established. Also, since any entity using NASA facilities for launching a payload is obliged to accept the inter-party waiver, if two NASA users are involved in a collision between a payload of one user and space refuse created by the other user and if the user responsible for the space refuse is negligent, the claimant State will have no cause of action against the negligent State.

In matters involving space refuse, a particularly severe defect of the NASA Launch Agreement is its failure to set a termination date at which time contractual responsibility for space objects remaining in outer space would expire. For purposes of liability, Article V, s. 3(e) of the Launch Agreement provides that

> "STS Operations" means all Space Transportation System activity, all Payload activity, and all related tangible personal property (which includes ground support, test, training and simulation equipment) activity.[237]

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236 Nesgos, supra, note 176 at 87. (emphasis added) See Article V, ss. 3(b)-(d) of the NASA Launch Agreement, supra, note 232.

237 Ibid.; note 232. (emphasis added)

For a payload, such as a telecommunication or meteorological satellite, which is "deployed or jettisoned" during STS operations, STS Operations end (1) when the payload impacts on Earth; or (2) if it is retrieved by the Orbiter, when the payload is removed (i) from a US government installation; (ii) the Orbiter itself, if it lands in other than a government installation, or (iii) a US government vehicle transporting the payload from the government installation or Orbiter, whichever occurs last.[238] "This aspect of the agreement could continue into perpetuity", since it "applies to all users on all shuttle flights".[239] As a result, a claimant State would be excluded from initiating a liability claim if, for example, a telecommunication satellite launched for it by NASA in 1988 suffered damage resulting from a collision with a space object launched by NASA in 1980.

There is no reason in principle why this perpetuity rule would not apply if the collision were between the satellite launched by NASA in 1988 and a breakup fragment of the satellite launched by NASA in 1980. However, the question may be raised as to whether the NASA Launch Agreement was meant to extend to circumstances such as these, notwithstanding the intent of the Agreement "to provide the broadest possible

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[238] Article V, s. 3(e)(2), NASA Launch Agreement, ibid.

[239] Tepfer, supra, note 235 at 210.

waiver of liability and avoid the prospect of any action".[240] In this instance, an argument can be made that both the technical and legal status of the satellite launched in 1980 have changed from "active payload" to "space refuse". Technically, movement of the item of space refuse cannot be controlled and, unlike the active payload, is therefore unpredictable in its orbital path. Legally, the Launch Agreement is without jurisdiction over space refuse, since it is intended to cover payload activity, not the activity of space refuse created therefrom.

The inter-party waiver also raises the question of whether parties to the Liability Convention can derogate by bilateral agreement from the principle of fault contained in Article III.[241] Article 41(1) of the Vienna Convention allows for modification if the treaty under consideration provides for modification or if

> the modification is not prohibited by the treaty and:
> (i) does not affect the enjoyment by the other parties of their rights under the treaty or the performance of their obligations;
> (ii) does not relate to a provision, derogation from which is incompatible with the effective execution of the object and purpose of the treaty as a whole.[242]

It has been suggested that "[a]ltering the liability regime for damages in space ... would not likely to run counter" to

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240 Nesgos, supra, note 176 at 87. See also, Article V, s.3(a), NASA Launch Agreement, supra, note 232.

241 Nesgos, ibid., at 87-88.

242 Supra, note 81.

this provision,[243] a point of view fortified by the focus of the negotiators of the Liability Convention on damage occurring on the ground and to aircraft in flight[244]. However, in view of the fact that derogation from Article III would eliminate the only express space law provision for compensation for damage caused by space refuse in outer space, the object and purpose of the Liability Convention, as expressed in paragraphs 3 and 4 of its Preamble,[245] cannot be carried out. Therefore, the proposed derogation would be incompatible with the execution of the Convention.

To date, the inter-party waiver has "worked well" for shuttle activities. However, an "obvious reason ... it has not been questioned or subject to judicial scrutiny is because no inter-party damage has been caused to date. Whether it will hold intact in the future remains to be seen."[246]

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243 Nesgos, supra, note 176 at 88.

244 Supra, text accompanying notes 205-206.

245 Preamble, pars 3 and 4 of the Liability Convention, supra, note 16, state:

> Taking into consideration that, notwithstanding the precautionary measures to be taken by States and international intergovernmental organizations involved in the launching of space objects, damage may on occasion be caused by such objects,
>
> Recognizing the need to elaborate effective international rules and procedures concerning liability for damage caused by space objects and to ensure, in particular, the prompt payment under the terms of this Convention of a full and equitable measure of compensation to victims of such damage, ...

246 Nesgos, supra, note 176 at 87.

(iii) Elements of Fault

The decision to base damage in outer space on fault has been subject to harsh criticism. This reaction is not surprising since issues such as those arising under Article III of the Liability Convention were not "meaningfully" dealt with during Convention negotiations.[247] Article III has been described as "meaningless in the context of space law" for application to space objects in general,[248] let alone to space refuse. Criticisms include the failure to define fault, absence of a standard of care and the inability to establish negligence.

The failure to define fault is a defect[249] aggravated at international law due to different interpretations of the term. "Fault" may be considered subjective or objective; the latter implies a pre-existing legal duty, while the former implies a finding of blameworthiness such as that in the law of negligence. It has been suggested that subjective fault is applicable to the Liability Convention, since objective fault is no more than a restatement of a basic principle of State liability under international law.[250]

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247 See, supra, text accompanying notes 207-209.

248 Firestone, supra, note 224 at 767.

249 Christol, supra, note 35 at 268 and Firestone, ibid., at 761.

250 F.K. Schwetje, **Managing Outer Space Traffic in the Future** (Montreal: McGill University, 1985) 251, citing J. Pfeifer, "International Liability for Damage Caused by Space Objects" (1981), Zeitschrift für Luft und Weltraumrecht 215 at

In addition, there is no indication in Article III of what duty of care is required to give rise to fault[251] or what standard of care is necessary for establishing reasonableness[252]. The absence of a standard of care has been viewed as a fundamental flaw since "no system is readily applicable to space law disputes in absence of standards of conduct for space activity",[253] either promulgated at international law or developed through case law[254]. Without a body of substantive law, litigation of space tort cases will be impossible.[255]

Several standards have been proposed as a basis for allocating fault. A launching State would be negligent if it (1) abandoned deliberately an active satellite where the technology existed to retrieve it;[256] (2) failed to maintain the required spacing between satellites in GEO;[257] (3) failed to place a potentially inactive satellite in a disposal

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[251] Firestone, supra, note 224 at 761.

[252] See, id.; Jasentuliyana, supra, note 178 at 395, and Christol, supra, note 35 at 368.

[253] Firestone, ibid., at 767.

[254] Although the Liability Convention was invoked following the Kosmos 954 incident, no case law resulted since the issues arising from the incident were never adjudicated; see, supra, A/2(d).

[255] Firestone, supra, note 224 at 762-72.

[256] Young, supra, note 82 at 299.

[257] Schwetje, supra, note 250 at 248.

orbit;[258] (4) failed to mitigate the production of space refuse,[259] or (5) refused to remove space refuse resulting from its space activities[260].

Even if all standards of care have been met, a collision between two active satellites may still not give rise to a cause of action in negligence under Article III: "For almost all spacecraft, once the satellite is placed in orbit, the launching State has neither the ability to foresee a future collision nor the ability to make the substantial manoeuvre to avoid one".[261] For example, predictions of possible collisions between an active satellite and a manned spacecraft such as the STS orbiter can only be made 12-24 hours in advance; when two unmanned active satellites are involved, the prediction time is even less.[262] Therefore, it is highly likely that the predictive ability will decrease even further when one of the objects is space refuse, since that object will be uncontrolled and may not be detectable.

(iv) Application of the Rationale for Fault-based Liability to Damage Caused by Space Refuse

A question, not yet addressed in the literature, arises as to whether the public policy arguments put forward for

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258 Id.

259 Swenson, supra, note 181 at 86.

260 Schwetje, supra, note 250 at 248.

261 Swenson, supra, note 181 at 80.

262 Id.

fault-based liability provide a suitable foundation on which to base liability resulting from damage caused by space refuse in outer space. The rationale for fault in Article III of the Liability Convention is based on the equality of States in undertaking space activities. Once space objects are in outer space, States participating in space activities are presumed to have accepted the risks involved. Moreover, it is said to be in the interest of the international community to give freedom to those conducting and developing space activities, unless they commit a fault.[263]

It is argued that if absolute liability, which applies when space objects cause damage on the ground or to aircraft in flight,[264] were invoked for damage to space objects in outer space, the result would be "absurd ... and sometimes unjust".[265] For example, if two active satellites collided and destroyed one another, each State would have to pay the other compensation. The owner of the more valuable satellite, even if that State were totally at fault, would receive

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[263] Foster, supra, note 35 at 154-55. See also, P. McGarrigle, "Hazardous Biological Activities in Outer Space" (1984), 18 Akron LR 103 at 135 and Lachs, supra, note 119 at 126.

[264] Article II of the Liability Convention, supra, note 16, states:

> A launching State shall be absolutely liable to pay compensation for damage caused by its space object on the surface of the earth or to aircraft in flight.

[265] Matte, supra, note 35 at 161.

greater compensation based solely on the value of a satellite -- surely an instance of an unjustifiable windfall.[266]

While this injustice may arise in the event of collisions between two active satellites, to extend the fault régime to a collision between an active satellite and a debris fragment, or any other class of space refuse, would be equally absurd and unjust. In a situation involving damage caused by space refuse, application of the rationale for absolute liability makes better sense for two reasons.

First, space flight and space activities may be considered ultrahazardous or abnormally dangerous activities.[267] Since its early days, space law has accepted the approach that States which undertake activities based on technological development are responsible for the results arising from those developments.[268] The proliferation of space refuse is one

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266 US Senate Report on Liability Convention, supra, note 4 at 27-28 and Matte, id.

267 McGarrigle, supra, note 263 at 105; US Senate Report on Liability Convention, ibid., at 26, and Heard, supra, note 224 at 184. Several elements are considered when determining what constitutes an "abnormally dangerous activity": (i) existence of a high degree of risk of harm to persons or property; (ii) likelihood that the resulting harm will be great; (iii) inability to eliminate the risk with reasonable care; (iv) extent to which the activity is not a matter of common usage; (v) whether the location of the activity is inappropriate for carrying out that activity, and (vi) the extent to which the value of the activity to the community is outweighed by its dangerous attributes; McGarrigle, ibid., at 104, citing Restatement (Second) of Torts, s. 520 (1967). Criteria (iv), (v) and (vi) "do not really add much to the determination and are already considered to be of minor importance"; ibid., at 111.

268 Lachs, supra, note 119 at 125.

such result. In these situations, "responsibility [should be] imputed to the person or entity making the initial decision to engage in the activity which exposes others to risks where possibly no amount of foresight or feasible protective measures may avert injuries"[269]. Therefore, in cases where space refuse causes damage, those who create the risk should bear the cost of protecting persons and property in outer space as well as the space environment itself,[270] particularly since (1) the exercise of due care by the claimant State will not avoid the risk;[271] (2) claimant States should not be penalized for the understandable inabilities of the negotiators of the Liability Convention to predict the future with any great deal of accuracy,[272] and (3) it makes little sense to protect the interests of third-party States on Earth from space refuse, while failing to protect the interests of those same States in outer space from those same risks -- especially if generation of space refuse can be prevented by State action.

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[269] US Senate Report on Liability Convention, supra, note 4 at 26.

[270] McGarrigle, supra, note 263 at 135.

[271] See, supra, text accompanying notes 261-262. If due care cannot avoid risks posed by active satellites to one another, it is unlikely to be significant in avoiding risks from space refuse. It is possible that the best way to avoid the hazards posed by space refuse, especially in LEO, will be to refrain from undertaking space activities; see, supra, Chapter One: D/2(a), particularly text accompanying notes 357-359.

[272] Supra, text accompanying notes 205-209.

Second, absolute liability is considered necessary when it is unlikely that fault can be established. In this situation fault-based liability leads to injustice: If a State causes damage through negligent conduct when carrying out its space activity and if negligence cannot be proved, that State carries out its activities at the expense of other States.[273]

In the outer space context and particularly when space refuse is being considered, problems of establishing the proof necessary for discovery procedures and evidential matters are magnified.[274] Although the fault rationale holds that launching States are in the best position to assess the presence of fault and adduce evidence toward that end, the present state of space technology makes proof of fault a difficult task at best,[275] even for the most advanced space powers. Lack of detection capabilities and identification techniques[276] may not even be effective in determining which of two colliding active satellites is responsible for the damage.[277] Such proof may be impossible to establish in a particular case involving space refuse, since anything smaller

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273 See US Senate Report on Liability Convention, supra, note 4 at 25-26.

274 Firestone, supra, note 224 at 763.

275 Foster, supra, note 35 at 155 and Schwetje, supra, note 250 at 252.

276 See, supra, Chapter One: C/2.

277 Swenson, supra, note 181 at 80.

than 4 cm. is "virtually impossible" to track at present.[278] As a result, potential claimant States may tend to refrain from the "costly and time-consuming investigations" necessary to establish proof of fault, "and simply bear their own losses".[279] Therefore, where space refuse is involved, application of the absolute liability rationale would relieve a claimant State of the onerous task of establishing fault.

(c) Conclusion

The question of recovery for damage caused by space refuse in outer space is not adequately addressed. Until this situation is rectified, it is meaningless to consider either the quantity of damages available or the procedure for obtaining compensation. Damage to the outer space environment per se is beyond the scope of the Convention. As with the Registration Convention, the meaning of "space object" is extremely restricted, excluding most classes of space refuse. At the root of the problem is the failure to give sufficient consideration to liability in outer space when the Liability Convention was being drafted. As a result, it is uncertain whether the scope of the Convention includes space refuse. Moreover, examination of the fault-based liability régime of Article III reveals that the question of foreseeability of

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[278] M.S. Smith, "Protecting the Earth and Outer Space Environment: Problems of On-Orbit Space Debris" (1982), 25 Colloquium Law of Outer Space 45 at 50.

[279] Matte, supra, note 35 at 161.

damage is unresolved, the scope of eligible claimants is severely limited, the basic elements of fault are undefined and application of the rationale for fault-based liability to damage caused by space refuse is hardly justifiable.

B/ REGULATION OF SPACE REFUSE

1. INTERNATIONAL LAW

The potential and actual harms which have already resulted from man's modification of his Earth-bound environment may be attributed more to a state of mind than a lack of information. Technological man has always seen himself as a dominator with the ability to change and control his natural and artificial surroundings as he sees fit.[280]

Legal rules for environmental protection evolved with man's increased understanding of the nature of ecological systems and of his place in the terrestrial system.[281] On an international level, environmental law has developed from a system in which disputes regarding environmental harms were settled on an inter-State level, to a true international system where it is now recognized that protection of the global environment is the responsibility of mankind.[282]

Environmental protection on a universal scale necessitates a conception of man as steward, tending the environ-

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[280] For an analysis of the concept of man as dominator of nature, see W. Leiss, **The Domination of Nature** (Boston: Beacon Press, 1974) particularly and J.A. Livingston, **One Cosmic Instant: Man's Fleeting Supremacy** (Boston: Houghton Mifflin, 1973) generally.

[281] Ecology is the science which studies the interrelationships between the natural environment and its elements. For an excellent introduction to this subject, see J.H. Storer, **The Web of Life** (NY: Signet Books, 1953).

[282] See Kiss, supra, note 125.

ment for future generations.[283] This perception is slowly evolving in practice and is tentatively beginning to replace the idea that the domination of nature is the inherent right of man.

Man has been carrying out activities in outer space for more than 30 years now. Has he learned his Earthly history lessons? To what extent does international law provide for protection of the outer space environment, including the Moon and other celestial bodies? Article IX of the Outer Space Treaty will be examined in some detail, since it is said to be the basic provision in space law for environmental protection. Applicable provisions in the Moon Agreement and other legal instruments relating to space law will also be considered. The principles of international environmental law and Article VI of the Outer Space Treaty are not addressed here, since they fail to establish the necessary specific regulatory régime.[284]

(a) Environmental Protection in Outer Space and on the Moon and Other Celestial Bodies

(i) The Sci-lab Perception

The attitude of the scientific community toward outer space during the early years of space exploration and use is

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283 Livingston, supra, note 280 at 154. See also, L. White Jr., "The Historical Roots of Our Ecologic Crisis" (1967), 155 Science 1203.

284 For a comprehensive discussion of international responsibility as it pertains to space refuse, see, supra, A/4.

of seminal importance. How the scientist valued outer space had a profound influence on the drafters of outer space law in general and Article IX of the Outer Space Treaty[285] in particular.

Shortly after the 4 October 1957 launching of Sputnik I, the question of environmental harms caused by outer space activity was raised.[286] However, the major scientific bodies involved with space activities were concerned with protecting the outer space environment only insofar as it affected the interests of their professional endeavours.

The scientific community in the late 1950s regarded outer space "essentially as a pure scientific laboratory",[287] but also recognized the possibility that harmful effects could result from experiments in outer space[288]. Consequently, to protect the unique research opportunities ushered in by the space age, the International Council of Scientific Unions(ICSU), a non-governmental organization composed of representatives of international scientific unions and national scientific organizations, formed the Committee on

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285 Supra, note 14.

286 I. Szilagyi, "Protection of the Outer Space Environment: Questions of Liability" (1982), 25 **Colloquium Law of Outer Space** 53 at 53.

287 Christol, supra, note 2 at 131.

288 I.A. Vlasic, "The Growth of Space Law 1957-65: Achievements and Issues", [1965] **Yrbk Air & Space L** 365 at 391-92.

Contamination by Extraterrestrial Exploration (CETEX).[289] That committee drew attention to the fact that "early exploration attempts or ill-considered experiments ... might result in biological, chemical or radiological contamination of the lunar or planetary surfaces such as to complicate or render impossible further studies of scientific importance".[290] CETEX sought to discourage space activities which could not create or convey meaningful data, while condoning the risks involved in space exploration as long as they could be justified by the scientific value of the experiment.[291] Contamination was avoided, therefore, to maintain the purity of the "newly accessible laboratory".[292]

When CETEX was disbanded in 1959, ICSU assigned its work to the Committee on Space Research (COSPAR), a special committee of the Council.[293] Interest and concern about the possible effects of space experiments on "the composition and structure of the Earth's atmosphere" led COSPAR to establish a Consultative Group on the Potentially Harmful Effects of Space

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289 Christol, supra, note 2 at 132.

290 UN GAOR, **Eighteenth Session of the First Committee,** A/C.1/SR.1345 (COSPAR Observer, 5 December 1963) par 2.

291 Christol, supra, note 2 at 132.

292 Id.

293 UN GAOR, **Eighteenth Session of the First Committee,** A/C.1/SR.1345 (COSPAR Observer, 5 December 1963) par 2.

Experiments (COSPAR-CG) in May 1962.[294] The mandate of the COSPAR-CG included examining the possible effects of back contamination[295] and "any proposed experiment or other space activities that might have potentially undesirable effects on other scientific activities and observations",[296] determining whether these experiment did have a potentially harmful effect[297] and submitting appropriate recommendations to the Executive Council of COSPAR[298].

In its 1964 Report to the Executive Council,[299] the COSPAR-CG concluded that some possible pollution-related

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294 UN GAOR, "Report to the Executive Council of the Committee on Space Research (COSPAR) of the COSPAR Consultative Group on the Potentially Harmful Effects of Space Experiments", International Co-operation in the Peaceful Uses of Outer Space[:] Committee on the Peaceful Uses of Outer Space, A/5785 (13 November 1964) Annex III at 5 [hereafter COSPAR-CG report].

295 See UN GAOR, COPUOS, First Session of the Scientific and Technical Sub-Committee, A/AC.105/C.1/SR.4 (COSPAR Observer, 29 August 1962) 7. Forward contamination takes place through the introduction of undesirable elements into outer space by some form of human intervention, while back contamination arises as a result of the introduction of undesirable extraterrestrial matter into the environment of Earth or undesirable use of such matter by similar human intervention; Gorove, supra, note 2 at 55-56.

296 UN GAOR, Eighteenth Session of the First Committee, A/C.1/SR.1345 (COSPAR Observer, 5 December 1963) par 2.

297 J.A. Johnson, "Pollution and Contamination in Outer Space" in M. Cohen (ed.), Law and Politics in Space (Montreal: McGill University Press, 1964) 37 at 42.

298 UN GAOR, COPUOS, First Session of the Scientific and Technical Sub-Committee, A/AC.105/C.1/SR.4 (COSPAR Observer, 31 May 1962) 7.

299 COSPAR-CG report, supra, note 294.

alterations "could cause interference in future experiments or can be considered harmful in other ways" and that further studies were necessary;[300] that no interference resulted from the Project West Ford orbiting dipoles;[301] and that since contamination of the Moon and planets raised the question of whether terrestrial organisms would interfere with any ecological system, especially that of Mars, it was important not to jeopardize "the value of information" that could be gained from studies of Mars[302].

COSPAR adopted a resolution on the basis of this report, which stated that "harmful contamination" of the upper atmosphere was unlikely, based on present and expected rates of experimental rocket launches; that any future experiments similar to West Ford were to be evaluated by the scientific community prior to their initiation to ensure they did not interfere with other scientific research; that "all practical steps should be taken" to avoid contamination of Mars until adequate standards of sterilization were developed and to set temporary sterilization levels for space vehicles engaged in planetary landing, atmosphere penetration and deep lunar drilling; and that States should "urge" the appropriate authorities to postpone the launching of planetary entry and

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300 Ibid., Appendix I at 6 and 8.

301 Ibid., Appendix II. Regarding Project West Ford, see, infra, text accompanying notes 309-312.

302 Ibid., Appendix III at 10-11.

landing vehicles until there was a final determination of acceptable sterility levels.[303]

The Scientific and Technical Sub-Committee of COPUOS at its Third Session in 1964 supported the COSPAR resolution.[304] However, the language of this Sub-Committee statement considerably weakened the effect of the COSPAR resolution.[305] COPUOS adopted this recommendation,[306] and in so doing, felt that the issue of possible interference with space activities had been settled in a manner satisfactory to all concerned.[307] However, some States, notably India and the Soviet Union, expressed reservations.[308]

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303 UN GAOR, "Resolution Adopted by the Executive Council of COSPAR on 20 May 1964", International Co-operation in the Peaceful Uses of Outer Space[:] Committee on the Peaceful Uses of Outer Space, A/5785 (13 November 1964) Annex II at 1-2 [hereafter COSPAR resolution].

304 UN GAOR, COPUOS, Report of the Scientific and Technical Sub-Committee on the Work of Its Third Session (22 May-5 June 1964), A/AC.105/20 (23 June 1964) 16.

305 The Sub-Committee watered down the resolution by (i) substituting "full consideration" of the problem of possible interference for "taking all practical steps" to avoid such interference, since the former does not necessitate taking any steps; (ii) enabling Member States proposing the space experiments to decide whether consultation was appropriate, and (iii) requiring a standard only of "due consideration" in evaluating whether to abide by any scientific analysis.

306 UN GAOR, International Co-operation in the Peaceful Uses of Outer Space[:] Committee on the Peaceful Uses of Outer Space, A/5785 (13 November 1964) par 33.

307 UN GAOR, Committee on the Peaceful Uses of Outer Space, A/AC.105/PV.29 (Austria, 30 October 1964) 28.

308 UN GAOR, COPUOS, Third Session of the Legal Sub-Committee, A/AC.105/C.2/SR.29-37 (India, 13 March 1964) 80 and UN GAOR: Committee on the Peaceful Uses of Outer Space,

Both COSPAR and CETEX, then, were concerned with the effects of contamination and interference only in so far as they would be detrimental to other scientific activities in outer space. The 1964 report of the COSPAR-CG, the corresponding resolution of COSPAR and the ultimate adoption by COPUOS of the Scientific and Technical Sub-Committee statement lent legal credence to this concern.

The response of the COSPAR-CG to Project West Ford further reinforces the view of the scientific community as expressed by COSPAR and CETEX. West Ford was a communications experiment designed to release from a satellite 350-million long, hair-like copper filaments (dipoles) which were expected to form a narrow belt in space around Earth.[309] The scientific community, fearing that West Ford could possibly have a detrimental effect on "other scientific activities",[310] called for a halt to the experiment until it could be "established

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A/AC.105/PV.30 (India, 2 November 1964) 10; **Committee on the Peaceful Uses of Outer Space**, A/AC.105/PV.26 (USSR, 27 October 1964) 14, and **Committee on the Peaceful Uses of Outer Space**, A/AC.105/PV.32 (USSR, 4 November 1964) 9.

309 Johnson, supra, note 297 at 46. One purpose of the experiment was to assess the potential harms of the dipole belt "on space activities and other branches of science"; see UN GAOR, COPUOS, **United States Space Communication Experiment (Project West Ford)**, A/AC.105/15 (6 June 1963) 4 [hereafter West Ford].

310 West Ford, **ibid.**, at 6.

beyond doubt that no damage [would] be done to astronomical research".[311]

The question of possible interference by Project West Ford with other scientific activities was raised at the first meeting of the COSPAR-CG in March 1963, two months prior to the successful placement of the dipole payload in orbit.[312] Objections to Project West Ford turned on the perceived threat to the safety of future scientific space research and experimentation, with no consideration given to the risk of harm to the outer space environment per se.

This attitude expressed by the scientific community is a reflection of what I will call the sci-lab perception, the view that the value of outer space, including the Moon and other celestial bodies, is limited to its use as a laboratory for scientific activity and that any proposed space activity will be assessed as potentially harmful to the outer space environment if and only if it threatens the future use of outer space for scientific purposes.

In other words, outer space is "there" to be used as the users see fit and has no value in itself. According to the sci-lab perception, if rules are to be made for regulating contamination in outer space, they should ensure that space

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[311] Jenks, supra, note 109 at 35-36. See also, West Ford, id.

[312] West Ford, ibid., 7. However, it should be noted that the launch took place before the COSPAR-CG announced in 1964 that the experiment would not have "significantly harmful results"; see Jenks, id.

research will "yield the fruits we are entitled to expect from it".[313] The "temptation of ... limitless experimentation" is to be avoided to prevent jeopardizing the "health and life on our planet".[314] Granted, these objectives are worthy ones; however, what is missing is the idea that protection of the outer space environment is an end in itself.

Conceptually, supporters of the sci-lab perception are legal positivists. For them, the predominant use of outer space is based on the needs of the State; these needs are actualized through the imposition of legal rules. In contrast, environmentalists subscribe to the theory of natural law, wherein legal rules are subservient to the nature of man and become tools to encourage stewardship of the environment for future generations -- humankind, spacekind and whatever other life forms may exist in the universe.[315]

The sci-lab perception permeated all United Nations outer space law negotiations for environmental protection, beginning with the 1958 General Assembly (UNGA) debates on whether to

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[313] Jenks, ibid., at 40.

[314] Lachs, supra, note 119 at 114-15.

[315] Regarding legal positivism and natural law, see N.M. Matte (ed.), **Space Activities and Emerging International Law** (Montreal: Centre for Research in Air and Space Law, McGill University, 1984) 130-35; regarding "spacekind", see G.S. Robinson and H.M. White Jr., **Envoys of Mankind: A Declaration of First Principles for the Governance of Space Societies** (Washington, DC: Smithsonian Institution Press, 1986), and regarding the existence of other life forms, see I.S. Shklovskii and C. Sagan, **Intelligent Life in the Universe** (NY: Dell Publishing, 1966).

establish a committee on the peaceful uses of outer space and concluding with Article IX of the Outer Space Treaty, which, in the opinion of many, is believed to be the basic provision in the international law of outer space for protection of the outer space environment. As a result, the sci-lab perception substantially coloured the approach, content and effect of the final products of all these negotiations.

(ii) Ad Hoc COPUOS

The sci-lab perception was evident during the 1958 UNGA debates which led to the formation of the Ad Hoc Committee on the Peaceful Uses of Outer Space (Ad Hoc COPUOS)[316], and also influenced the decisions of that committee concerning the content, extent and rationale of future scientific research in outer space.

No doubt existed that the "ever more frequent excursions into outer space which man would make would be first and foremost for scientific purposes"[317] and that all States had the right to carry out these scientific activities[318]. States conducting or intending to conduct experiments in outer space

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[316] UN GAOR, Eighteenth Session of the First Committee, A/C.1/SR.982-995 (12-24 November 1958).

[317] UN GAOR, Eighteenth Session of the First Committee, A/C.1/SR.982 (Chile, 12 November 1958) pars 27-28.

[318] UN GAOR, Eighteenth Session of the First Committee, A/C.1/SR.987 (Costa Rica, 17 November 1958) par 12.

were to prevent harmful contamination in order to "safeguard celestial bodies for the sake of science".[319]

The Ad Hoc COPUOS was requested to report to the UNGA, inter alia, on recommendations for programmes for the peaceful uses of outer space.[320] In its 1959 Report, the Ad Hoc COPUOS cited contamination as an area for which international co-operation was necessary in order to ensure that various phases of space activities could be carried out.[321] Since certain space experiments could lead to biological, chemical or radiological contamination which might jeopardize further research and endanger possible extraterrestrial organisms, and since space vehicles on returning to Earth could contaminate the planet with extraterrestrial organisms, the Committee stated it was "desirable" to continue any research in progress "with a view to arriving at appropriate agreements to minimize the adverse effects of possible contamination".[322]

Contamination of outer space was to be avoided primarily to prevent Earthly material from "interfering with orderly scientific research". Although further studies were to be encouraged to prevent this interference and "other hazards to

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319 UN GAOR, Eighteenth Session of the First Committee, A/C.1/SR.985 (China, 14 November 1958) par 12.

320 Question on the Peaceful Uses of Outer Space, UNGA Res. 1348 (XIII) 13 December 1958, par 1(b).

321 UN GAOR, Report of the Ad Hoc Committee on the Peaceful Uses of Outer Space, A/4141 (14 July 1959) 44-47 [hereafter 1959 Report].

322 Ibid., at 47.

health and safety" which might be created by "space exploration activities", these studies were considered non-priority items, that is, those items which did "not yet appear ripe for solution".[323]

However, the 1959 Report made no mention of other safety and health hazards which space activities might create, the dangers that contamination posed to the outer space environment per se, or the need for research to assess the impact of contamination on the integrity of the Earth/space ecosystem and its sub-systems. The programme for prevention of contamination presented in the 1959 Report reflected the sci-lab perception by seeking "to protect space against the emergence of conditions that could impede scientific and technological investigations".[324]

(iii) 1963 General Debates

The 1963 general debates of COPUOS and its two sub-committees further illustrate the influence that the sci-lab perception had on drafters of outer space law.

One representative felt that the Legal Sub-Committee should work

> to prevent the use of outer space for experiments which endangered human life or which changed the space environment in such a way that the possibility of obtaining more important scientific information was jeopardized. On rare occasions, a major experiment of such a type might be so important as to be

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[323] Ibid., at 69 and 61.

[324] Christol, supra, note 2 at 132.

desirable in the interests of science, but it should first be discussed and cleared.[325]

One delegation to the Scientific and Technical Sub-Committee included a scientist who was convinced that any harm to future space experiments resulting from high altitude nuclear explosions "would be very insignificant in comparison with the value of the information gained" and that most experiments which had resulted in contamination of the upper atmosphere "had been of sufficient scientific interest to be justified".[326]

More significantly, a recommendation of the Scientific and Technical Sub-Committee during its Second Session,[327] which was subsequently approved by COPUOS, recognized the importance of the problem of preventing harmful interference, but limited the scope of this prevention to experiments which "may affect present or future scientific activities". Only in these circumstances were assurances sought that the experiments "would not adversely change the space environment or adversely affect experiments in space".[328] Therefore, the

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[325] UN GAOR, COPUOS, Second Session of the Legal Sub-Committee, A/AC.105/C.2/SR.22 (India, 24 April 1963) 7.

[326] UN GAOR, COPUOS, Second Session of the Scientific and Technical Sub-Committee, A/AC.105/C.1/SR.12-20 (Canada, 29 May 1963) 91-92.

[327] UN GAOR, COPUOS, Report of the Scientific and Technical Sub-Committee on the Work of Its Second Session, A/AC.105/14 (5 June 1963) 9.

[328] UN GAOR, International Co-operation in the Peaceful Uses of Outer Space[:] Committee on the Peaceful Uses of Outer Space, A/5549 (24 September 1963) 8.

sci-lab perception governed in COPUOS when deciding the criteria for avoiding potentially harmful interference. States supporting the Sub-Committee recommendation "based on a genuine fear as to the safety of outer space"[329] would be forced to accept this limitation. As a result, a pivotal recommendation which could have had an influential effect on the prevention of potentially harmful interference was substantially deflated.[330]

(iv) Paragraph 6 of the Legal Declaration

Paragraph 6 of the Legal Declaration[331] states:

> In the exploration and use of outer space, States shall be guided by the principle of co-operation and mutual assistance and shall conduct all their activities in outer space with due regard for the corresponding interests of other States. If a State has reason to believe that an outer space activity or experiment planned by it or its nationals would cause potentially harmful interference with activities of other States in the peaceful exploration and use of outer space, it shall undertake appropriate international consultations before proceeding with any such activity or experiment. A State which has reason to believe that an outer space activity or experiment planned by another

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329 UN GAOR, Committee on the Peaceful Uses of Outer Space, A/AC.105/PV.21 (UAR, 12 September 1963) 3.

330 UN GAOR, Committee on the Peaceful Uses of Outer Space, A/AC.105/PV.22 (Italy, 13 September 1963) 3 and 10.

331 Supra, note 19. The Legal Declaration has been accepted by the vast majority of States as evidence of customary international law; see UN GAOR, COPUOS, Fifth Session of the Legal Sub-Committee, A/AC.105/C.2/SR.57 (12 July 1966), particularly US at 5 and USSR at 10. As such, the principles it espouses -- regardless of their generality-- are binding on all States not parties to the Outer Space Treaty.

State would cause potentially harmful interference with activities in the peaceful exploration and use of outer space may request consultation concerning the activity or experiment.

Paragraph 6 was the first attempt to enunciate a principle calling for "international consultations in the case of dangerous activities",[332] and took into account the recommendations of the 1962 Report of the Scientific and Technical Sub-Committee, which invited the attention of COPUOS to the "urgency and importance" of preventing potentially harmful interference with the peaceful uses of outer space[333]. According to this principle, freedom of space experimentation would be limited only to the extent that member States did not comply with the rules of co-operation and respect for the interests of others.[334]

Paragraph 6 was viewed as a statement of principle which would guard against any outer space activities that could cause potentially harmful interference with space activities of other States.[335] Although Paragraph 6 did not include a

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332 UN GAOR, Eighteenth Session of the First Committee, A/C.1/SR.1342 (USSR, 2 December 1963) par 14.

333 UN GAOR, International Co-operation in the Peaceful Use of Outer Space[:] Additional Report of the Committee on the Peaceful Uses of Outer Space, A/5549/Add.1 (27 November 1963) Annex (Chairman, Legal Sub-Committee) 3 [hereafter Additional Report]. See also, UN GAOR, Eighteenth Session of the First Committee, A/C.1/SR.1345 (Czechoslovakia, 5 December 1963) par 9.

334 UN GAOR, Eighteenth Session of the First Committee, A/C.1/SR.1343 (Hungary, 3 December 1963) par 14.

335 Additional Report, supra, note 333, Annex (US) 7.

procedure for consultation, COPUOS could use this provision as "a starting point for working out the necessary preventative and precautionary measures and for finding means for their effective international application".[336]

Objections to Paragraph 6 were raised regarding both the lack of a specific obligation to consult if proposed experiments could modify the natural environment of Earth in a manner which would threaten the human race or the interests of other States,[337] and the failure to provide for an international authority with power to act if consultations failed[338]. However, a more important objection was not recorded: Whether to undertake international consultation was a subjective decision based on the reasonable belief of the State proposing the activity, thereby leaving it to the undertaking State to determine whether its activity would cause potentially harmful interference.

The principle of co-operation was upheld by all during negotiations for the Legal Declaration.[339] The importance of a co-operative effort for preventing space activities which might impede or make difficult the space activities of other

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[336] UN GAOR, Eighteenth Session of the First Committee, A/C.1/SR.1343 (Hungary, 3 December 1963) par 17.

[337] Additional Report, supra, note 333, Annex (Canada) 10.

[338] UN GAOR, Eighteenth Session of the First Committee, A/C.1/SR.1344 (Peru, 4 December 1963) par 24.

[339] UN GAOR, COPUOS, Second Session of the Legal Sub-Committee, A/AC.105/C.2/SR.22 (USSR, 24 April 1963) 4.

States was strongly stressed by the Soviet Union.[340] The "due regard" principle limits the absolute freedom of use and exploration of outer space, since due regard for the interests of other States requires States to consider the effects of their space activities on the world community of States.[341]

Paragraph 6 establishes a link between the general principles of co-operation and due regard in sentence 1 and the two more specific provisions concerning potentially harmful activities in sentences 2 and 3.[342] This connection limits both the need for co-operation and mutual assistance and the interests for which States should have due regard, to those situations in which consultation is necessary, that is, in cases where States have a reasonable belief that space activities or experiments could harmfully interfere with other space activities.[343] In sentence 2, a State carrying out a space activity has an obligation to consult prior to undertaking that activity if that State has a "reason to believe"

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[340] UN GAOR: Sixteenth Session of the First Committee, A/C.1/SR.1210 (USSR, 4 December 1961) par 25 and Committee on the Peaceful Uses of Outer Space: A/AC.105/PV.5 (USSR, 20 March 1962) 11 and 26, and A/AC.105/PV.10 (USSR, 10 September 1962) 38.

[341] Several States accepted the due regard principle on this basis; see UN GAOR, COPUOS, Second Session of the Legal Sub-Committee: A/AC.105/C.2/SR.21 (Canada, 23 April 1963) 6 and A/AC.105/C.2/SR.22 (24 April 1963) - India at 7 and Japan at 12.

[342] Jenks, supra, note 109 at 40.

[343] Regarding the narrow definition of corresponding interests, see, infra, text accompanying notes 354-357.

that the proposed activity could cause potentially harmful interference with other space activities. In sentence 3, States other than the State carrying out the activity have a right to request consultation if they have "reason to believe" that the space activity under consideration could cause harmful interference with other space activities.

It is important to note that sentences 2 and 3 refer to "space activities" as well as "experiments". As a result, commercial and public service activities as well as scientific ones are subject to consultation. Therefore, States may avoid consultation under the "reasonable belief" rule for a greater number of activities. In practical terms, the ability to control or prevent possible harmful interference has been diminished.

More significantly, application of the sci-lab perception is likewise extended: Any proposed space activity will be assessed as potentially harmful to the outer space environment if and only if it threatens the future use of the outer space environment for scientific, commercial or public service activities. It may seem at first glance that increasing the scope of activities in Paragraph 6 would reduce the risk of environmental harm. However, the fact that the majority of activities capable of causing environmental harm are unlikely to threaten the future use of outer space for scientific, commercial or public service activities, makes the possibility of such a reduction remote.

(v) Article 10 of the US Draft Treaty and Article VIII of the USSR Draft Treaty

When US President Lyndon B. Johnson stated on 7 May 1966 that a treaty on general principles of space law was necessary, one principle which he proposed be included was: "Studies should be made to avoid harmful contamination".[344] Several months following this statement, the United States and the Soviet Union submitted to COPUOS draft proposals for general principles to govern space law.

Article 10 of the US Draft Treaty states:

> States shall pursue studies of and, as appropriate, take steps to avoid harmful contamination of celestial bodies and adverse changes in the environment of the Earth resulting from the return of extraterrestrial matter.[345]

The first legislative provision submitted to COPUOS for avoidance of contamination, this principle follows the suggestion of President Johnson, which likely resulted from the acceptance of the COSPAR resolution by COPUOS in 1964.[346] The US Draft Treaty contained no specific reference to Paragraph 6 of the Legal Declaration.

Article VIII of the USSR Draft Treaty states:

> In the exploration and use of outer space, 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,

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344 Dembling, supra, note 139 at 6.

345 UN GAOR, COPUOS, Draft Treaty Concerning the Exploration of the Moon and Other Celestial Bodies, A/AC.105/C.2/L.12 (US, 11 July 1966) [hereafter US Draft Treaty].

346 See, supra, text accompanying notes 303-308.

> including activities on celestial bodies, with due regard for the corresponding interests of other States. States Parties to the Treaty shall conduct research on celestial bodies in such a manner as to avoid harmful contamination. If a State Party to the Treaty has reason to believe that an outer space activity or experiment planned by it or its nationals would cause potentially harmful interference with activities of other States Parties in the peaceful exploration and use of outer space, including activities on celestial bodies, it shall undertake appropriate international consultations before proceeding with any such activity or experiment. A State Party to the Treaty which has reason to believe that an outer space activity or experiment planned by another State Party would cause potentially harmful interference with activities in the peaceful exploration and use of outer space, including activities on celestial bodies, may request consultation concerning the activity or experiment.[347]

This provision broadened the scope of Paragraph 6 of the Legal Declaration by including a specific reference to activities on celestial bodies, thereby ensuring that activities in outer space included activities on celestial bodies. The introduction of the principle of avoidance of contamination in sentence 2 parallels that of Article 10 in the US Draft Treaty and can also likely be attributed to the acceptance by COPUOS of the COSPAR resolution.

A comparison of sentence 2 of USSR Article VIII with US Article 10 is revealing. The scope of activities is broader in Article 10. "Studies" in Article 10 includes "research" in sentence 2 of Article VIII as well as commercial and govern-

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[347] UN GAOR, COPUOS, Draft Treaty on Principles Governing Activities of States in the Exploration and Use of Outer Space, the Moon and Other Celestial Bodies, A/AC.105/C.2/L.13 (USSR, 11 July 1966) [hereafter USSR Draft Treaty].

ment-sponsored activities. The use of "studies" is significant, since scientific, commercial and public service activities are all bound by the contamination avoidance rule. Furthermore, a parallel is achieved with the "space activity" and "experiment" categories for which consultation is deemed necessary.

The type and scope of contamination to be avoided differs. Sentence 2 of Article VIII is ambiguous in the type of contamination it prohibits. Inclusion of forward contamination is almost certain, while back contamination maybe inferred since "to avoid harmful contamination" has no indirect object. While Article 10 is more specific, providing for both forward and back contamination, the duty there is less strict. Only "steps to avoid" contamination need be taken, whereas it is mandatory that contamination be avoided in sentence 2 of Article VIII. "Steps to avoid" could mean that contamination resulting from an activity would be permissible, notwithstanding the steps taken to avoid the contamination, thereby nullifying any recommended contamination procedure. However, regardless of whether a strict or narrow interpretation is applied, it is the sci-lab perception which will ultimately determine what types of contamination will be avoided -- those which prevent future space activities.

Sentence 2 of Article VIII does not contain specific references to either the Moon or outer space. Therefore, sentence 2 may be interpreted to mean that harmful contamination is to be avoided only on celestial bodies other than the Moon. This provision could mean that when carrying out research on the Moon and in outer space, States need not avoid harmful contamination as long as the co-operation and due regard requirements of sentence 1 are met. In Article 10, the contamination to be avoided varies with the location: "Harmful contamination" is to be avoided on celestial bodies, while "adverse changes" are to be avoided on Earth. The use of a different expression for each location raises serious concerns. Since adverse changes (for example, transformation of planetoid geography by an accidental explosion) may not necessarily constitute harmful contamination, such changes could be permitted on celestial bodies. Similarly, importation to Earth of an extraterrestrial organism, which results in harmful contamination (for example, elimination of a bird species) would be permissible as long as adverse changes (such as permanent poisoning of the terrestrial water supply) do not occur. In addition, as with sentence 2 of Article VIII, the lack of specific reference to the Moon and outer space implies that harmful interference need not be avoided there.

Both proposals are enlightening for what they do not say. Neither considers a standard for permissible interference, mentions the avoidance of specific activities, nor makes it mandatory to avoid activities which could harmfully contaminate the outer space environment **per se**. Furthermore, no prohibitions are invoked.[348]

These omissions illustrate the application of the sci-lab perception to treaty drafting. Because COPUOS had approved the COSPAR resolution, the US and USSR drafters were faced with the political necessity of incorporating into their respective texts a rule for avoiding harmful contamination. The results of their efforts ensure that any sector of the outer space environment will be preserved for future commercial, public service or scientific activity. For example, consider the situation where contamination from a commercial activity irreversibly transforms the ecological balance of a celestial body. If that celestial body were unfit for future commercial, public service or scientific activity, the rule would be breached. In no other case would a legal sanction apply. This change would not be considered "harmful contamination" if the three uses mentioned above were still possible; and even if the contamination were considered harmful, it could be argued that any **bona fide** efforts taken to avoid contamination failed. Any attempt to protect the environment of that celestial body would be either incidental or temporary, based on the need for future use.

(vi) Article IX of the Outer Space Treaty

Article IX of the Outer Space Treaty states:

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[348] Kolossov, **supra**, note 6 at 53.

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, including the Moon and other celestial bodies, 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 and also adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter and, where necessary, shall adopt appropriate measures for this purpose. If a State Party to the Treaty has reason to believe that an activity or experiment planned by it or its nationals in outer space, including the Moon and other celestial bodies, would cause potentially harmful interference with activities of other States Parties in the peaceful exploration and use of outer space, including the Moon and other celestial bodies, it shall undertake appropriate international consultations before proceeding with any such activity or experiment. A State Party to the Treaty which has reason to believe that an activity or experiment planned by another State Party in outer space, including the Moon and other celestial bodies, would cause potentially harmful interference with activities in the peaceful use and exploration of outer space, including the Moon and other celestial bodies, may request consultation concerning the activity or experiment.

The sci-lab perception goes to the root of Article IX-- harmful activities, that is, those space activities which contaminate and those which interfere with other space activities. Several commentators have pointed out the difficulties of defining "harmful", "contamination" and "interference",[349] and have assumed that scientists will

[349] See, eg, Gorove, supra, note 2 at 62-63; G.C.M. Reijnen, "Some Aspects of Environmental Problems in Space Law" (1977), 26 Zeitschrift für Luft und Weltraumrecht 23 at 23; Kolossov, ibid., and Dembling and Kalsi, supra, note 158 at 140-41. For the definition of contamination, see, infra, text

ultimately be the ones to define these terms[350]. However, the sci-lab perception provides the test for "harm", a test which has nothing whatsoever to do with science. An activity will be harmful only if it interferes with the future use of outer space, the Moon and other celestial bodes for space activities. This rule is based on the short-term goals of man, not the laws of nature as interpreted by the scientist. Therefore, harmful interference and harmful contamination have no direct connection with environmental concerns. Environmental protection in Article IX is only a fortuitous by-product.

Although it attempts to regulate the unfettered freedom to use and explore the outer space environment,[351] Article IX is ineffectual as an environmental protection regulation because the approach when drafting the text was from the sci-lab perspective, not from an environmental point of view. From an environmental perspective, protection of the outer space environment and its sub-systems is the priority. The regulator examines the total system under consideration, identifies the needs of the system and provides rules to manage that system in an ecologically beneficial manner. These rules would prohibit or limit activities if those

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accompanying notes 410-415.

350 See, eg, M. Miklody, "Some Remarks on the Status of Celestial Bodies and Protection of the Environment" (1982), 25 Colloquium Law of Outer Space 13 at 13 and Dembling and Kalsi, ibid., at 140.

351 Gorove, supra, note 2 at 60.

activities would harm the system. Accordingly, total classes of activities could be eliminated. With a sci-lab approach, the utility of the activity prevails. The regulator looks to the activity, then provides rules to prohibit or limit that activity to the extent that it will impede the future use of the system for other activities. Consequently, since all activities are prima facie acceptable, the scope of delimitation is much narrower.

For example, suppose space mining activities occur on a celestial body. Following exploitation, strip-mining has defaced the celestial body, outer space itself is contaminated, but further mining is possible. Under Article IX, no rule or regulation has been broken. From an environmental perspective, the activity would likely have been prohibited or, if permitted, would have been limited so as to avoid harm to the celestial body and its surrounding space environment.

Sentence 1 of Article IX serves as an example of the practical application of the principle of international cooperation and mutual assistance, which was considered to be the keystone of the Outer Space Treaty.[352] From this basic treaty principle could be derived the duty of States to

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352 UN GAOR, Twenty-First Session of the First Committee, A/C.1/SR.1493 (Belgium, 17 December 1966) par 49.

prevent contamination and to co-operate in scientific research.[353]

The principle that due regard should be given to the corresponding interests of States was considered to be "one of the most important points" in space law.[354] However, these corresponding interests are severely limited in Article IX for three reasons. First, unlike Paragraph 6 of the Legal Declaration, which applies to all States, Article IX of the Outer Space Treaty applies only to States parties to that treaty.[355] Second, as the representative of France contended, "corresponding interests" are restricted to potentially harmful interference with space activities, harmful contamination to celestial bodies and adverse changes to the environment of Earth from back contamination caused by extraterrestrial organisms.[356] He argued that concern for corresponding interests should also account for certain effects on the territories of States in the broadest sense, including territorial waters, airspace and land-based installations, and

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353 UN GAOR, COPUOS, Fifth Session of the Legal Sub-Committee, A/AC.105/C.2/SR.60 (Argentina, 15 July 1966) 2-3.

354 UN GAOR, COPUOS, Fifth Session of the Legal Sub-Committee, A/AC.105/C.2/SR.68 (Canada, 26 July 1966) 10 [hereafter Article IX debate].

355 The issue as to the rights and obligations of non-party States under the Outer Space Treaty is unresolved; see UN GAOR, COPUOS, Fifth Session of the Legal Sub-Committee, A/AC.105/C.2/SR.71 and Add.1 (Romania, 4 August 1966) 18-19.

356 UN GAOR, Committee on the Peaceful Uses of Outer Space, A/AC.105/PV.47 (France, 17 April 1967) 27.

should specifically include possible harmful effects resulting from direct broadcast satellites, weather modification, "certain uses of high altitude photography" and congestion in outer space resulting from overcrowding of satellites, radio frequencies and spent satellites.[357] Third, the sci-lab test for "harmful" further delimits the corresponding interests by not restricting those activities which, while not posing a risk to future space activities, may harm the outer space environment.

The contamination provision in sentence 2 of Article IX refers to forward and back contamination,[358] thereby combining US Article 10 with sentence 2 of USSR Article VIII. Front contamination is to be avoided in outer space and on the Moon as well as celestial bodies.[359] The provision in US Article 10 for "taking steps to avoid harmful contamination" where appropriate was modified and incorporated into sentence 2 of Article IX to allow for the adoption of appropriate measures, where necessary, to avoid both harmful contamination in the

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[357] See also, Christol, **supra**, note 2 at 139, citing J. Sztucki, "International Consultation and Space Treaties" (1975), 17 Colloquium Law of Outer Space 159.

[358] Article IX debate, **supra**, note 354, USSR at 3 and UN GAOR, COPUOS, Fifth Session of the Legal Sub-Committee, A/AC.105/C.2/SR.63 (US, 20 July 1966) 2-3.

[359] Article IX debate, **id.**

entire outer space environment and adverse changes to the environment of Earth caused by back contamination.[360]

A bid by the Japanese delegation to have sentence 2 of Article IX amended to include more detailed regulation of contamination[361] was rejected. It was felt that since the issue of forward and back contamination was at an early stage of development and since the COSPAR-CG was consulting on the matter, care had to be taken not to establish "too rigid procedures" which might hinder future research.[362] The Japanese delegation, however, was not convinced that its proposal was covered by reading the due regard principle together with the proposed contamination provision, as "some delegations" had suggested.[363] Rather, the Japanese delegation "suspected that the space powers had not accepted its amendment mainly because they feared that it might tie their hands in future activities on celestial bodies".[364]

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[360] For a plea to expand the scope for avoidance of contamination, see the statements of the representative of India in UN GAOR, COPUOS, Fifth Session of the Legal Sub-Committee: A/AC.105/C.2/SR.71 and Add.1 (4 August 1966) 9 and A/AC.105/C.2/PR.71 (4 August 1966) 23-25.

[361] Article IX debate, supra, note 354 at 6 and UN GAOR, COPUOS, Fifth Session of the Legal Sub-Committee, A/AC.105/C.2/SR.58 (Japan, 13 July 1966) 7.

[362] Article IX debate, ibid., US at 7.

[363] UN GAOR, COPUOS, Fifth Session of the Legal Sub-Committee, A/AC.105/C.2/PR.71 (Japan, 4 August 1966) 38-40.

[364] UN GAOR, COPUOS, Fifth Session of the Legal Sub-Committee, A/AC.105/C.2/SR.71 and Add. 1 (Japan, 4 August 1966) 13.

Perhaps most importantly, the category of activities for which harmful contamination was to be avoided was widened to include exploration as well as research, combining "pursue studies" from US Article 10 and "conduct research" from USSR Article VIII. As indicated above, "studies" could include commercial, public service and scientific activities. Indeed, Article IX of the Outer Space Treaty refers to "pursuing studies" and "conducting exploration", totally eliminating the more restrictive concept of "research" and, in so doing, extends the avoidance of harmful contamination to commercial and public service activities in addition to scientific activities.

Sentence 2 offers no direct protection for the outer space environment. States undertaking scientific, commercial or public service space activities are obliged to avoid harmful forward and back contamination and to adopt measures, where appropriate, for avoiding such contamination. However, the test for "harmful" is based on the sci-lab perception and its future-use standard, even though the safeguards contained in the principle of avoidance of harmful contamination were considered to include maintenance of a contamination-free outer space environment as a legitimate interest[365].

In addition, it was never intended that the protection offered by sentence 2 would apply to the environments of outer

365 UN GAOR, Twenty-First Session of the First Committee, A/C.1/SR.1493 (Sweden, 17 September 1966) 26.

space, the Moon and celestial bodies per se. Although it was suggested that possible environmental harms should be given a priority ranking, this listing was only to avoid interference of one activity with another;[366] although the freedom of States to use and explore outer space was limited to non-threatening activities, threatened activities included only those which impinged on State sovereignty;[367] and although it was argued that State parties should exercise "maximum care"[368] to preserve the resources and milieu of celestial bodies,[369] this preservation was solely to further scientific utility[370]. Moreover, no activity is barred, only avoided, thereby allowing for harmful contamination by default; although avoidance may be the intent, it need not be the result. Therefore, widening the scope of activities subject to the avoidance of harmful contamination only served to legitimize contaminating activities, thereby allowing for a greater possibility of environmental harms in outer space and on the Moon and other celestial bodies.

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366 UN GAOR, COPUOS, **Fifth Session of the Legal Sub-Committee**, A/AC.105/C.2/PR.7 (France, 17 April 1966) 26.

367 **Ibid.**, at 27.

368 UN GAOR, COPUOS, **Fifth Session of the Legal Sub-Committee**, A/AC.105/C.2/SR.71 and Add.1 (Japan, 4 August 1966) 13.

369 UN GAOR, COPUOS, **Fifth Session of the Legal Sub-Committee**, A/AC.105/C.2/SR.58 (Japan, 13 July 1966) 7 and Article IX debate, **supra**, note 354, Japan at 6.

370 Article IX debate, **id.**

The duty of States to impose limits on space activities which may cause harmful contamination is ambiguous and minimal. Regulations must be appropriate -- where necessary. Although the test for necessity is not explicitly subjective, the negotiating history of Article IX and its results belie an objective test, especially when the "reasonable belief" test for consultation is taken into account. In any case, the sci-lab perception will govern what measures are appropriate; whether the test is subjective or objective becomes a matter of the quantity of contamination, not the quality of the environment.

Sentences 3 and 4 apply to scientific, commercial or public service space activities which may cause potentially harmful interference with space activities of other States. As a consequence of the sci-lab perception, harmful interference arises only where the future use of outer space, the Moon and other celestial bodies for space activities will be prevented. Once again, environmental protection is incidental.

The consultation principle incorporated into sentences 3 and 4 of Article IX provides a forum for the scientific analysis of activities which could cause potentially harmful interference. This provision differs from USSR Article VIII only to the extent that the scope of exploration and use is widened to include the Moon as well as outer space and other celestial bodies.

The consultation provision in both sentences was intended to serve a double duty. Not only would appropriate consultations be required if activities or experiments of one State might interfere with activities of other States, but every State party undertaking such an activity "would be obliged to transmit to other parties information on these activities".[371]

For a sentence 3 consultation to arise, the State undertaking the consultation must have a reasonable belief that its space activity would prevent the future use of outer space for commercial, public service or scientific activities. If such a consultation situation arose, a State undertaking consultation would be obliged to provide information as to the nature of the activity or experiment for which consultation was sought. However, there is no requirement that the information be either complete or delivered in time for sufficient study prior to consultation.

In addition, no procedures for consultation or disputes arising therefrom are enumerated in sentence 3. Since Article III of the Outer Space Treaty provides that space activities are to be carried out in accordance with international law,[372] States could apply the dispute resolution procedures developed under international law and provided for in Chapter VI of the UN Charter. However, to invoke established Earth-bound

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[371] UN GAOR, COPUOS, Fifth Session of the Legal Sub-Committee, A/AC.105/C.2/SR.68 (USSR, 13 July 1966) 7.

[372] For the text of Article III, see, supra, note 118.

procedures for resolution of outer space disputes may distort the issue to fit the procedure. Different characteristics of outer space and terrestrial environments demand different approaches.[373]

In sentence 4, for a State to accede to a request for consultation, the requesting State must have a reasonable belief and must demonstrate that the space activity of the undertaking State could cause potentially harmful interference with the space activities of other States; that is, the activity would prevent the future use of outer space for commercial, public service or scientific activities. If and when a State acceded to such a request, the requesting State would have a right to receive from the acceding State any additional information as to the nature of the activity for which consultation was sought. But as with a sentence 3 consultation, this information need be neither complete nor timely. Also, consultation procedures are lacking.

Sentence 4 suffers from an additional weakness in that it provides no obligation for the State undertaking the activity to accede to the request for consultation.[374] However, it has been argued that since the Outer Space Treaty has compulsory force, "it would therefore be compulsory to comply with

[373] H. DeSaussure, "Maritime and Space Law: Comparison and Contrasts (An Oceanic View of Space Transport)" (1981), 9 J Space L 93 at 103. See also, Matte, supra, note 315 at 175-79.

[374] Article IX debate, supra, note 354, Lebanon at 9.

requests for which it provided".[375] On this basis, accession to a request for consultation would be compulsory if the requesting State could demonstrate that potentially harmful interference would result from the proposed activity. But as with the information provision, the lack of a time element for initiating consultation following such a request effectively negates its compulsory force.

States wishing to protect the outer space environment per se will fall under the sentence 4 provision, but only if they are parties to the Outer Space Treaty. Non-party States have no standing under the Treaty, although they may be able to invoke Paragraph 6 of the Legal Declaration since its principles have been accepted by almost all States as indicative of international customary law.[376] Although the reasonable belief test seems to be to the advantage of a requesting State in an environmental protection context, the sci-lab perception mitigates against the success of a request to consult: The requesting State must convince the undertaking State on the basis of the sci-lab test that its space activity could cause potentially harmful interference; since environmental protection stands outside the utilitarian nature of the sci-lab

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[375] Ibid., USSR at 9.

[376] It is reasonable to assume, however, that any State in a position to undertake space activities will become a party to the Outer Space Treaty prior to the time when its space activities are operational.

perception, success in preventing such an activity on purely ecological grounds is out of the question.

Finally, States carrying out space activities which result in harmful contamination will only be under a duty to consult if those activities also cause potentially harmful interference with other space activities. As with other instances of potentially harmful interference, the sci-lab perception narrows the application of this duty to consult to those instances in which future space activities would be prevented.

(b) Environmental Protection on the Moon and Other Celestial Bodies Elaborated

(i) Article 7 of the Moon Agreement

Article 7 of the Moon Agreement[377] enhances the environmental obligations found in the Outer Space Treaty through the expression of specific standards of behaviour to be followed on the Moon and other celestial bodies.[378]

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377 Supra, note 108.

378 Sterns and Tennen, supra, note 147 at 13-14. The progressive development in the Moon Agreement of specific provisions for environmental protection, based on the foundation established by the more general principles of the Outer Space Treaty, is consistent with the approach adopted by the UN for the orderly development of space law. According to this procedure, the broad guidelines of the Outer Space Treaty evolve when necessary in order to account for scientific and technological change or to resolve specific problems; see E. Galloway, "Agreement Governing Activities of States on the Moon and Other Celestial Bodies" (1980), 5 **Annals Air & Space L** 481 at 481-83. The Moon Agreement is one instance of the application of this procedure, with the enumeration of principles for environmental protection on the Moon and other celestial bodies being only one of several legal issues

Article 7 par 1 states:

> In exploring and using the moon, States Parties shall take measures to prevent the disruption of the existing balance of its environment, whether by introducing adverse changes in that environment, by its harmful contamination through the introduction of extra-environmental matter or otherwise. States Parties shall also take measures to avoid harmfully affecting the environment of Earth through the introduction of extraterrestrial matter or otherwise.

This paragraph overcomes many of the deficiencies found in sentence 2 of Article IX of the Outer Space Treaty[379] by supplementing "practically all lacuna's[sic] and controversies" found therein[380].

"Prevent disruption" is more comprehensive[381] than the duty in sentence 2 of Article IX to avoid harmful contamination in outer space and on the Moon and other celestial bodies, and adverse changes to Earth, since both "harmful contamination" and "adverse changes" must be avoided on the Moon. Moreover, the obligation to avoid these activities is

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addressed in the Agreement; see N.M. Matte, "Legal Principles Relating to the Moon" in Jasentuliyana and Lee, supra, note 38, 253 at 253-55.

379 Jasentuliyana, supra, note 178 at 394 and Qizhi, supra, note 211 at 1-2.

380 H.L. van Traa-Engelman, "Environmental Hazards from Space Activities: Status and Prospects of Environmental Control" (1982), 25 Colloquium Law of Outer Space 55 at 59.

381 Sterns and Tennen, supra, note 147 at 13.

now of "minor importance",[382] since "or otherwise" is intended to cover all forms of disruption[383].

By stating that the "existing balance" of Moon's environment is not to be disrupted, Article 7 moves away from the utilitarian demands of the sci-lab test and invites a scientific definition of "disruption", based on ecological principles. Although no specific standards are enumerated for determining when an activity contravenes the general obligation to prevent disruption of this existing balance,[384] the objective nature of scientific definition will increase the likelihood of agreement on this determination.

Article 7 par 2 of the Moon Agreement states:

> States Parties shall inform the Secretary-General of the United Nations of the measures being adopted by them in accordance with paragraph 1 of this article and shall also, to the maximum extent feasible, notify him in advance of all placements by them of radioactive materials on the moon and the purposes of such placements.

Unlike sentence 2 of Article IX which calls for adequate regulatory measures, where necessary, the Moon Agreement obliges its States Parties to give notice of all preventive measures taken, thereby increasing the effectiveness of the duty to prevent disruption[385]. Also, this paragraph implies that States must "take precautions for all missions" in order

382 van Traa-Engelman, supra, note 380 at 59.

383 Qizhi, supra, note 211 at 2.

384 Jasentuliyana, supra, note 178 at 394.

385 van Traa-Engelman, supra, note 380 at 59.

to prevent disruption.[386] While notice of preventive measures may be **ex post facto**, advance notice is necessary for placement of radioactive materials. However, the effect of this advance notice is weakened, since it need only be given "to the maximum extent feasible". As any State will probably be aware of any placement of radioactive materials well in advance of undertaking the activity, there should in principle be no need to delay notice.

The scope of the Moon Agreement encompasses the Moon, "orbits around or other trajectories to or around [the Moon]" and other celestial bodies in our solar system without their own specific legal régime.[387] Therefore, protection of the outer space environment **per se** and celestial bodies outside our solar system is excluded. Also, there is no guarantee that celestial bodies in our solar system, which may have separate legal régimes in the future, will be given Article 7 protection.

The inclusion of orbits and trajectories of the Moon within the scope of the Agreement could offer extensive

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[386] Sterns and Tennen, supra, note 147 at 13.

[387] Article 1 of the Moon Agreement, supra, note 108, states in part:

> 1. The provisions of this Agreement relating to the moon shall also apply to other celestial bodies within the solar system, other than the earth, except in so far as specific legal norms enter into force with respect to any of these celestial bodies.
> 2. For the purposes of this Agreement reference to the moon shall include orbits around or other trajectories to or around it.

protection for the near-Earth environment, depending on how Article 1 par 2[388] is interpreted. If orbits and trajectories are construed as areas of space rather than isolated locations in time, the scope of the Agreement could take in "all space in the plane of the Moon's orbit around Earth and enclosed in that orbit, since a trajectory to the Moon may be plotted anywhere in that plane".[389]

(ii) Article 15 par 2 of the Moon Agreement

Article 15 par 2 of the Moon Agreement[390] provides that a State party may request consultation if it reasonably believes that another State party has breached its duties under the Agreement or is interfering with the rights of the requesting State under the Agreement. It is mandatory that the State receiving this request enter into consultation without delay

388 Id.

389 Swenson, supra, note 181 at 81-82.

390 Article 15 par 2 of the Moon Agreement, supra, note 108, states:
A State Party which has reason to believe that another State Party is not fulfilling its obligations incumbent upon it pursuant to this agreement or that another State Party is interfering with the rights which the former State has under this agreement may request consultations with that State Party. A State Party receiving such a request shall enter into such consultations without delay. Any other State which requests to do so shall be entitled to take part in the consultations. Each State Party participating in such consultations shall seek a mutually acceptable resolution of any controversy and shall bear in mind the rights and interests of States Parties. The Secretary-General of the United Nations shall be informed of the results of the consultations and shall transmit the information received to all States Parties concerned.

and attempt to seek a mutually acceptable settlement. If such a settlement is not reached, the States involved must use appropriate peaceful means to settle the dispute.[391]

This provision eliminates several ambiguities found in sentences 2 and 4 of Article IX of the Outer Space Treaty[392]. On the Moon, consultation may be requested for all instances of contamination, not just those which are both "harmful" and cause "potentially harmful interference". Article 15 par 2 also extends the consultation procedure to any activity causing potentially harmful interference, if that activity would also disrupt the existing balance of the Moon's environment. As a result, activities which would have been excluded under Article IX of the Outer Space Treaty, due to the sci-lab

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[391] Article 15 par 3 of the Moon Agreement, ibid., states:

> If the consultations do not lead to a mutually acceptable settlement which has due regard for the rights and interests of all States Parties, the parties concerned shall take all measures to settle the dispute by other peaceful means of their choice appropriate to the circumstances and the nature of the dispute. If difficulties arise in connection with the opening of consultations or if consultations do not lead to a mutually acceptable settlement, any State Party may seek assistance of the Secretary-General, without seeking the consent of any other State Party concerned, in order to resolve the controversy. A State Party which does not maintain diplomatic relations with another State Party concerned shall participate in such consultations, at its choice, either itself or through another State Party or the Secretary-General as an intermediary.

[392] For sentence 2 of Article IX of the Outer Space Treaty, see, supra, text accompanying notes 358-370; for sentence 4 of Article IX, see, supra, text accompanying notes 371-376.

test for "harmful",[393] may now be prohibited, even if they do not interfere with scientific, commercial or public service uses of the Moon.

The onus to determine whether the existing balance of the environment has been disrupted rests entirely on States other than the one undertaking the allegedly disruptive activity, since the undertaking State has no duty to consult if it reasonably believes that its activity may cause a disruption.[394] It is unclear whether any disruptive activity must be held in abeyance until a mutually acceptable settlement is reached. However, Article 15 par 2 guarantees that any request for consultation must be honoured promptly and facilitates the consultation procedure by outlining a dispute-resolution mechanism.

(c) Other Principles of International Law Relevant to Environmental Protection in Outer Space and on the Moon and Other Celestial Bodies

Other international legal agreements referring to outer space may contain provisions for protecting the outer space environment. Three such instruments are the Partial Nuclear Test Ban Treaty, the Environmental Modification Convention and

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[393] See, supra, B/1(a)(i) and text accompanying notes 349-351.

[394] However, sentence 3 of Article IX of the Outer Space Treaty, supra, text accompanying notes 371-373, still applies, thereby obliging the undertaking State to enter into consultation if it reasonably believes that any of its activities on the Moon could cause potentially harmful interference with activities of other States in outer space and on other celestial bodies, as well as on the Moon.

the ITU Convention. In addition, Article IV of the Outer Space Treaty and Article 3 of the Moon Agreement are applicable here.

(i) Partial Nuclear Test Ban Treaty

The Partial Nuclear Test Ban Treaty,[395] Article IV of the Outer Space Treaty and Article 3 of the Moon Agreement serve to protect the outer space environment, the Moon and other celestial bodies to the extent that they prohibit nuclear activities. Article I of the Partial Nuclear Test Ban Treaty prohibits, inter alia, all nuclear explosions in outer space.[396] Article IV of the Outer Space Treaty prohibits the placement of nuclear weapons in orbit around Earth, in outer space or on celestial bodies.[397] Article 3 of the Moon Agreement clarifies that the Outer Space Treaty prohibition includes the Moon as a celestial body and expands the scope of

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[395] Treaty Banning Nuclear Weapons Tests in the Atmosphere, in Outer Space and Under Water, 14 UST 1313, TIAS 5433 (5 August 1963).

[396] Article I par 1(a), ibid., states:
Each of the Parties to this Treaty undertakes to prohibit, to prevent and not to carry out any nuclear weapon test explosion, or any other nuclear explosion, at any place under its jurisdiction or control in the atmosphere; beyond its limits, including outer space; or under water, including territorial waters or high seas.

[397] Article IV par 1 of the Outer Space Treaty, supra, note 14, states:
States Parties to the Treaty undertake not to place in orbit around the Earth any objects carrying nuclear weapons or other weapons of mass destruction, install such weapons on celestial bodies, or station such weapons in outer space in any manner.

that prohibition to include orbits around and other trajectories to or around the Moon.[398] However, these provisions bind only States parties to the agreements and do not exclude the possible use of space refuse as a means of maintaining national security[399].

(ii) Environmental Modification Convention

The Environmental Modification Convention[400] prohibits military or other hostile uses of techniques which, through deliberate manipulation, could change the dynamics, composition or structure of outer space.[401] The effectiveness of

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[398] Article 3 par 3 of the Moon Agreement, supra, note 108, states:

> States Parties shall not place in orbit around or other trajectory to or around the moon objects carrying nuclear weapons or any other kinds of weapons of mass destruction or place or use such weapons on or in the moon.

Regarding Moon orbits and trajectories, see, supra, text accompanying notes 387-389.

[399] For military applications of space refuse, see, supra, Chapter One: B/3(b).

[400] Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques, UNGA Res. 31/72 (10 December 1976); 610 UNTS 151, 31 UST 333, TIAS 9614 (opened for signature 18 May 1977, entered into force 5 October 1978).

[401] Article I par 1, ibid., states:

> Each State Party to this Convention undertakes not to engage in military or other hostile use of environmental modification techniques having widespread, long-lasting or severe effects as the means of destruction, damage or injury to any other State Party.

Article II, ibid., states:

> As used in article I, the term "environmental modification techniques" refers to any technique for changing -- through the deliberate manipulation of natural processes -- the dynamics, composition or structure of the earth, including its biota, lithosphere, hydrosphere and atmosphere, or of outer space.

this provision as a regulatory mechanism for protection of the outer space environment **per se** could be severely limited, if application of the Convention is restricted to contracting States. Under this interpretation, only States parties to the Convention would be protected, to the exclusion of the outer space environment **per se**.[402]

Other limitations on the prohibition against environmental modification techniques are that only adhering or acceding States are bound by it and that these techniques may be used for peaceful purposes, as permitted by international law[403].

(iii) ITU Convention

The ITU Convention[404] and its accompanying Radio Regulations make no provisions for protection of the outer space

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"Environmental modification techniques include changes in weather or climate patterns, ocean currents, the state of the ozone layer or ionosphere, or upsetting the ecological balance of a region;" W.B. Wirin, "Constraints on Military Manned Activities in Outer Space". Paper prepared for presentation at Armed Forces Communications and Electronics Association Symposium on Man's Role in Space, Colorado Springs, CO, 3-6 August 1987, at 5.

[402] D.E. Reibel, "Prevention of Orbital Debris". Paper prepared for presentation at 30th Congress of the IISL, Brighton, 10-17 October 1987, at 5.

[403] Article III par 1 of the Environmental Modification Convention, **supra**, note 400, states:

> The provisions of this Convention shall not hinder the use of environmental modification techniques for peaceful purposes and shall be without prejudice to the generally recognized principles and applicable rules of international law concerning such use.

[404] International Telecommunication Convention--Nairobi, 1982 (Geneva: ITU, 1982).

environment per se, since non-communication aspects of space objects are not within the province of the ITU.[405] While Article 35 of the ITU Convention provides for avoidance of harmful interference with the radio frequencies of transponders on board space objects, the interference must be caused by the operating radio station of a space object, not by space refuse created by that station.[406]

2. APPLICATION OF INTERNATIONAL REGULATORY PROVISIONS TO THE ISSUE OF SPACE REFUSE

Discussions of the risks posed by space refuse reflect concerns that its continued proliferation will interfere with future space activities[407] and will damage economically and

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405 Perek, supra, note 92 at 36.

406 Article 35 par 1 of the ITU Convention, supra, note 404, states:

> All stations, whatever their purpose, must be established and operated in such a manner as not to cause harmful interference to the radio services or communications of other Members or of recognized private operating agencies, or of other duly authorized operating agencies which carry on radio service, and which operate in accordance with the provisions of the Radio Regulations.

Harmful interference has been defined as "[a]ny emission, radiation or induction which endangers the functioning of a radio navigation service or of other safety services, or seriously degrades, obstructs or repeatedly interrupts a radiocommunication service operating in accordance with the Radio Regulations"; R.S. Jakhu, The Legal Regime of the Geostationary Orbit (Montreal: McGill University, 1983) n.141.

407 See, eg, D.J. Kessler, "Orbital Debris Issues" (1985), 5 Advances in Space Res 3 and Kessler and Su, supra, note 208.

politically valuable space assets[408]. Yet based on the material in the preceding section, it may be concluded that international law does not directly address the issues raised by space refuse. There are neither prohibitions against its creation nor specific regulations for its avoidance, prevention or removal. To what extent, then, can the existing principles of international law be interpreted to provide for the regulation of space refuse?

(a) Outer Space, the Moon and Other Celestial Bodies

Space refuse is a harm which can be brought within the scope of Article IX of the Outer Space Treaty. Even with a restrictive interpretation of sentence 1,[409] due regard for the corresponding interests of other States in outer space requires that contracting States avoid creation of space refuse and attempt to reduce and remove any space refuse causing either harmful contamination of outer space, the Moon or other celestial bodies, or potentially harmful interference with space activities.

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408 See, eg, F.K. Schwetje, "Current US Initiatives to Control Space Debris". Paper prepared for presentation at 30th Congress of the IISL, Brighton, 10-17 October 1987, and M.G. Wolfe and L.P. Temple III, "Department of Defense Policy and the Development of a Global Policy for the Control of Space Debris". Pre-print of a paper prepared for presentation at 30th Congress of the IISL, Brighton, 10-17 October 1987.

409 See, supra, text accompanying notes 352-357.

Sentence 2 of Article IX[410] is of limited application. Generally, space refuse is not "harmful contamination". Contamination in sentence 2 refers at most to biological contamination caused by terrestrial organisms in outer space, and to chemical or radioactive contamination created during the course of scientific activities on the Moon and Mars.[411] Radioactive contamination by nuclear explosions must be eliminated from consideration since a prohibition against all nuclear explosions in outer space was enacted four years prior to the opening for signature of the Outer Space Treaty.[412] Moreover, prevention of biological contamination was the primary concern of COSPAR,[413] the international scientific body from which the Scientific and Technical Sub-Committee of COPUOS took its guidance[414]. Consequently, only microbiological organisms of terrestrial origin exceeding the probability

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[410] See, supra, text accompanying notes 358-370.

[411] See "Second Meeting of the ad hoc Committee on Contamination by Extraterrestrial Exploration, The Hague, March 9-10, 1959, Summary Recommendations" in G.S. Robinson, **Contamination of Earth's Ecosystem by Extraterrestrial Matter: United States Authority to Promulgate and Enforce Quarantine Regulations** (Montreal: McGill University, 1970) 235-41. See also, supra, text accompanying notes 289-290.

[412] See, supra, B/1(c)(i).

[413] Robinson, **supra**, note 411 at 45-46. COSPAR recommended that "the upper limit to the probability of contamination over the entire period of biological exploration of Mars or other planets" be one in 1,000; **ibid.**, at 243. NASA adopted this limit for its Apollo Moon missions; **ibid.**, at 46.

[414] For the relationship between COSPAR and the Scientific and Technical Sub-Committee of COPUOS in this matter, see, supra, text accompanying notes 299-307.

of causing biological contamination were intended to be covered by "harmful contamination".

At present, the only organisms falling under the sentence 2 duty would be those deliberately placed on board space objects for quarantine purposes, in order to lessen the risk of harm to Earth.[415] In this case, sentence 2 of Article IX would apply only if the material were accidentally released, since placement of the material in outer space is not "harmful contamination" per se. Moreover, sentence 2 neither prohibits such placement, since "harmful contamination" need only be avoided, nor subjects quarantined materials to control, since international regulation prior to launch is not mandatory. In addition, international consultation[416] on the advisability of using outer space for this purpose need not be initiated by the launching State, unless the danger resulting from the activity is "significant enough as judged by the experimenting party" to constitute a foreseeable danger[417] and, hence, a reasonable belief of potentially harmful interference.

Based on statements of the scientific and technical communities,[418] the United Nations[419] and authors in various

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[415] See McGarrigle, supra, note 263 at 108-112.

[416] See, supra, text accompanying notes 371-373.

[417] McGarrigle, supra, note 263 at 118.

[418] See, eg, Proceedings of COSPAR Workshops in (1985), 5 Advances in Space Res 3-96 and in (1986), 6 Advances in Space Res 97-158, and American Institute of Aeronautics and Astronautics (AIAA), "Space Debris" in Kessler and Su, supra, note 208 at 365.

technical and legal periodicals,[420] and taking into account the facts themselves concerning the risks posed by space refuse[421] and the probability of the occurrence of a risk event[422], it can be fairly concluded that, as required by sentence 3 of Article IX,[423] space-capable States now have a reasonable belief that their space activities which produce space refuse cause potentially harmful interference with other space activities -- even if the strict interpretation of "harm", as required by the sci-lab perception,[424] is invoked. Despite this evidence, a space-capable State may argue that no reasonable belief exists since (i) its calculations indicate that the risk of the harm from any space refuse produced is within acceptable limits, or (ii) the quantity of space refuse produced will not be sufficient to harm other space activities. In rebuttal, it can be pointed out that the reasonable belief required in sentence 3 is based on the potential for harmful interference and that it is this potential which is beyond dispute.

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419 UN GAOR, COPUOS, **Space Debris[:] A Status Report Submitted by the Committee on Space Research**, A/AC.105/403 (6 January 1988).

420 See, infra, Appendix II: Selected Bibliography - B.

421 See, supra, Chapter One: B.

422 See, supra, Chapter One: D/2.

423 See, supra, text accompanying notes 371-373.

424 See, supra, B/1(a)(i) and text accompanying notes 349-351.

If the requisite reasonable belief can be established, any space-capable State has a duty to act in good faith with its international obligations,[425] as expressed in sentence 3 of Article IX of the Outer Space Treaty, and enter into international consultations in order to reduce the present quantity of space refuse and to control the creation of additional refuse, prior to undertaking space activities with refuse-creating potential. However, the effectiveness of the sentence 3 consultation provision is severely limited: its generalities could result in indefinite delays[426] and recommendations resulting from consultation need not be binding.

The sentence 4 provision of Article IX is applicable, since the potential risks of space refuse are beyond dispute. Notwithstanding the weakness of this consultation provision,[427] States should exercise their legal right to request consultation, if they can determine which space activity will produce the space refuse. States need not be space-capable to initiate a sentence 4 request; indeed, those States with ground-based space activities such as radio astronomy may also make a request and may have more concrete grounds for a

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[425] Article 26 of the Vienna Convention, supra, note 81, states:

> Every treaty in force is binding upon the parties to it and must be performed by them in good faith.

[426] See, supra, text accompanying notes 371-373.

[427] See, supra, text accompanying notes 371-376.

reasonable belief of potentially harmful interference. If enough requests for consultation arise, it is possible that the pressure of international public opinion will force undertaking States into acceding to consultation, since they are not legally required to do so.

(b) The Moon and Other Celestial Bodies Elaborated

The Moon Agreement is not a dominant force for preventing harms caused by space refuse at present, since it has been ratified by only six States,[428] none of which is a space power. However, the limited number of ratifications is basically due to disagreement over the international régime for exploiting the natural resources of the Moon.[429] If the most recent statement of US space policy is any indication,[430] accession to the Moon Treaty by space-capable nations may be forthcoming in the future.

If the space nations accede to the Moon Agreement, contracting States would have a duty to avoid creating any space refuse which disrupts the existing balance of the

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[428] Austria, Chile, the Netherlands, Pakistan, the Philippines and Uruguay have ratified the Moon Agreement.

[429] See N.M. Matte, "The Common Heritage of Mankind and Outer Space: Toward A New International Order for Survival" (1987), 12 Annals Air & Space L 313 at 321-23.

[430] US President Ronald Reagan's National Space Policy, announced 11 February 1988, calls for, inter alia, the establishment of a lunar base; "Space Policy Outlines Program to Regain US Leadership", AvWk&SpTech (22 February 1988) 20.

environment.[431] Moreover, with the provision for mandatory and prompt consultation,[432] it is more likely that disruptive activities would be prevented. Application of these principles would result in a much stricter regulatory régime, since an environmental perspective, rather than a sci-lab one, is employed.[433]

From the environmental point of view, two issues deserve immediate attention: (i) the definition of "disruption" which, in turn, indicates the necessity of establishing tests for determining disruption thresholds in outer space and on the Moon for various types of space refuse, and (ii) whether the area enclosed by the plane of the Moon's orbit around Earth is considered to be within the scope of the Moon Agreement[434].

(c) Other Relevant Principles

The Partial Nuclear Test Ban Treaty, Article IV of the Outer Space Treaty and Article 3 of the Moon Agreement combine to prevent the creation of radioactive space refuse resulting from nuclear explosions, whether for military or peaceful purposes.[435] However, these provisions do not address the potential risks of radioactive space refuse, which could arise

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[431] See, supra, text accompanying notes 381-384.

[432] See, supra, text accompanying notes 390-394.

[433] See, supra, text following note 312.

[434] See, supra, text accompanying notes 387-389.

[435] See, supra, text accompanying notes 396-398.

if active, retired or stored satellites with nuclear power sources on board are involved in collisions or are otherwise fragmented.[436]

The Environmental Modification Convention is a two-edged sword. While prohibiting hostile uses of environmental modification techniques, it condones, by positive law, these same techniques for peaceful purposes.[437] Since an argument can be made that creation of space refuse is an environmental modification technique,[438] such creation is permissible to the extent that its use accords with peaceful purposes and conforms with Article IV of the Outer Space Treaty[439]. Also, if the narrow interpretation of Article I of the Environmental Modification Convention is followed,[440] widespread, long-

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[436] See, supra, Chapter One: B/1(d).

[437] See Article I par 1 and Article III par 1, Environmental Modification Convention, supra, notes 401 and 403, respectively.

[438] Deliberate manipulation of natural forces (eg, gravity and electro-chemical energy) places space refuse in outer space and thereby upsets the ecological balance of a region of outer space. See Article II, Environmental Modification Convention and Wirin, supra, note 401.

[439] Peaceful purposes may be "non-aggressive" military ones. In addition, placement of all weapons systems in outer space is not prohibited. Therefore, the possibility exists that debris clouds could be created for "peaceful" purposes. See Wirin, ibid., at 3-4 and M.L. Stojak, **Legally Permissible Scope of Current Military Activities in Space and Prospects for Their Future Control** (Montreal: McGill University, 1985) 184-212.

[440] See, supra, text accompanying notes 354-357.

lasting or serious harm[441] need not be avoided in the outer space environment.

Although non-communication aspects of space objects are beyond the jurisdiction of the ITU,[442] the risks posed by space refuse may decrease the ability of satellites in GEO to perform their communication functions effectively. Therefore, the question may be raised as to whether the ITU, as part of its regulatory régime in GEO, could not be responsible for controlling space refuse and establishing minimum separation distances between satellites.[443]

(d) Conclusion

Regulation of space refuse according to international law is by inference at best. In most instances, that inference is very weak; yet even if it were stronger, creation of substantial amounts of space refuse would be permissible due to the inadequacies of the existing international legal régime.

3. INTERNATIONAL POLICY

The harms posed by space refuse call for remedies comprising clearly-stated positive law. To date, inter-

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441 "Widespread" refers to an area of several hundred square kilometres; "long-lasting" to approximately one season, and "severe" to significant disruption or harm to human life, natural and economic resources or other assets; Stojak, supra, note 439 at 175.

442 Supra, B/1(c)(iii).

443 For actions of the ITU regarding space refuse, see, infra, B/3(b).

national organizations have only begun to address the legal implications of space refuse. The present positions of COPUOS, the ITU, ESA and INTELSAT on this issue and the effect of these positions on the regulation of space refuse are discussed in this section.

(a) Committee on the Peaceful Uses of Outer Space (COPUOS)

Involvement of COPUOS with the question of space refuse arose indirectly from matters concerning the removal of satellites from GEO and the potential hazards arising from the use of nuclear power sources (NPS) on board space objects. A discernable interest in space refuse as an issue per se has developed only recently.

(i) Satellite Removal from GEO

The issue of space refuse as a specific environmental problem in outer space arose as an ancillary matter during discussions on the efficient use of GEO. It was proposed in 1981 that "efforts should be made to provide all geostationary satellites with the means to remove themselves from [GEO] at the end of their active lifetimes".[444]

The idea that removal of inactive satellites from GEO was a solution to problems of congestion and collision was subsequently reiterated and expanded. The Report of the

444 UN, UNISPACE 82, **Efficient Use of The Geostationary Orbit**, A/CONF.101/BP/7 (16 January 1981) par 81 [hereafter **Efficient Use report**].

Second United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE 82)[445] recommended that satellite owners be responsible for the removal.[446] A study on the feasibility of closer spacing in GEO proposed that such removal be mandatory as soon as the relevant technology became available.[447] From this study, it may also be inferred that removal was not considered to be a complete solution to the risk of collision in GEO; the report concluded that "it may be necessary" to study the collision problem in GEO and to devise methods of collision avoidance.[448]

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445 UNISPACE 82 was held in Vienna, 9-20 August 1982, with 94 States as participants and 45 inter-governmental and non-governmental organizations as observers. The Conference was convened to consider both the complex scientific and technical issues arising from the use of outer space for peaceful purposes, and the legal implications of these issues; N. Jasentuliyana and R. Chipman (eds.), **International Space Programmes and Policies. Proceedings of the Second United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE), Vienna, August 1982** (Netherlands: Elsevier Science Publishers, 1984) v. For the Proceedings of UNISPACE 82, see, **ibid.**, or UN, **UNISPACE 82, Report of the Second United Nations Conference on the Exploration and Peaceful Uses of Outer Space**, A/CONF.101/10 (31 August 1982) [hereafter UNISPACE 82 report].

446 UNISPACE 82 report, **ibid.**, par 283. Removal was one proposed alternative for avoiding collisions in GEO. Another was the use of orbits other than GEO for active payloads; **ibid.**, par 285.

447 UN GAOR, COPUOS, **The Feasibility of Obtaining Closer Spacing of Satellites in Geostationary Orbit**, A/AC.105/340 Rev.1 (22 April 1985) Part Two, par 3(e) [hereafter Closer Spacing report]. Once again, removal was perceived as an alternative to the use of non-geostationary orbits for avoiding collisions; see, **ibid.**, Part One, pars 88-90.

448 Closer Spacing report, **ibid.**, Part One, par 123.

Emphasis on removing satellites from GEO received strong support from the developing nations, which view such removal as an advancement toward the equitable, equal and economic use of GEO, as provided for by Article 33 of the ITU Convention[449]. Specific reference to removal for these purposes was made in the draft principles for governing GEO, submitted by four equatorial States in 1984.[450] While acceptance of this proposal would lessen the space refuse hazard in GEO, the principle of removal may well be a source of conflict rather than a basis for compromise: Its rationale is a political extension of the debate over the status of GEO.[451] The

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[449] Article 33 of the ITU Convention, supra, note 404, states:

> In using frequency bands for space radio services Members shall bear in mind that radio frequencies and the geostationary satellite orbit are limited natural resources and that they must be used efficiently and economically, in conformity with the provisions of the Radio Regulations, so that countries or groups of countries may have equitable access to both, taking into account the special needs of developing countries and the geographical situations of particular countries.

[450] Principle VIII of the UN GAOR, COPUOS, Draft General Principles Governing the Geostationary Orbit, a joint working paper of Columbia, Ecuador, Indonesia and Kenya, A/AC.105/C.2/L.147 (29 March 1984), states that

> States and/or international organizations operating their space objects in the Geostationary Orbit shall take necessary actions to remove non-operational or unutilized space objects from the Orbit.

[451] Certain equatorial States issued the Bogota Declaration in 1976 as a response to their concern that the limited natural resource of GEO would be unavailable for their needs when they had developed the technology necessary for placing satellites in that orbit. The Declaration stated that equatorial States had sovereignty over the corresponding segments of GEO above their territory and that prior notice to the appropriate equatorial State was necessary before user

political tenor of this debate is further evidenced by the lack of a provision for the removal of inactive satellites in the corresponding set of draft principles for the use of GEO submitted by the industrialized States.[452] Nevertheless, it was an industrialized State which suggested in 1986 that the possibility of adopting the removal principle be considered by the ITU at its 1988 World Administrative Radio Conference (WARC), on the use of GEO by fixed satellite systems.[453]

(ii) Nuclear Power Sources (NPS)

In the aftermath of the Kosmos 954 incident,[454] States were alerted to the potential hazards associated with space-based NPS. Since then, the Legal Sub-Committee of COPUOS has developed a proposal containing seven draft principles on

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States could place space objects in GEO. See Declaration of the First Meeting of Equatorial Countries, ITU Doc. WARC-BS (17 January 1977) 81-E. For an enumeration of the issues raised by the status of GEO, see, eg, UN GAOR, COPUOS, Report of the Legal Sub-Committee on the Work of Its Twenty-Fifth Session (24 March-11 April 1986), A/AC.105/370 (5 May 1986) pars 14-22.

452 Cf, the positions of the developing countries and the industrialized States in a Comparative Table prepared by Indonesia, in UN GAOR, COPUOS, Report of the Legal Sub-Committee on the Work of its Twenty-Fifth Session, A/AC.105/370 (5 May 1986) 25-27.

453 UN GAOR, COPUOS, Twenty-Fifth Session of the Legal Sub-Committee, A/AC.105/C.2/SR.446 (Sweden, 22 April 1986) par 34. See also, infra, B/3(b).

454 See, supra, A/2(d).

space-based NPS.[455] The draft principles concerned with safety guidelines are relevant to the space refuse issue.

Principle 2 provides that space objects with NPS on board shall undergo "a thorough safety assessment prior to launching". While "thorough" is intended to indicate that the assessment applies to quality-control programmes for the development of NPS elements as well as to the safety and reliability of each stage of the mission of the space object, the launching State determines the acceptable level of risk.[456] This subjective determination could lead to different degrees of "thoroughness", thereby defeating the quest for a standardized level of risk in matters involving NPS.

Principle 3 enumerates the guidelines and criteria for safe use to be followed in undertaking a safety assessment. The risk of radiological contamination must conform with recommendations of the International Commission on Radiologi-

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[455] For the 1987 revised draft of these principles, see UN GAOR, COPUOS, **The Elaboration of Draft Principles Relevant to the Use of Nuclear Power Sources in Outer Space**, Working Paper submitted by Canada, A/AC.105/C.2/L.154/Rev.2 (31 March 1987) [hereafter NPS Principles]. Two principles were approved by the Legal Sub-Committee in 1986: notification of re-entry of space objects carrying NPS and assistance to States following notice of re-entry; UN GAOR, COPUOS, **Report of the Scientific and Technical Sub-Committee on the Work of Its Twenty-Fourth** Session, A/AC.105/383 (3 March 1987) par 66. No further approvals were forthcoming in 1987.

[456] UN GAOR, COPUOS, **Twenty-Sixth Session of the Legal Sub-Committee**, A/AC.105/C.2/SR.452 (Canada, 19 March 1987) par 29. The rationale given in support of this subjective test undercuts the need for international standards for NPS: "It would seem presumptuous for the international community to act as a substitute for the launching State"; id.

cal Protection (Principle 3, par 1). To prevent radiological contamination on Earth by space objects with NPS on board, States must try to place such space objects in a nuclear-safe orbit (NSO) for periods as long as 300 years.[457] If an NSO is not used, space objects with NPS on board must be designed for "transfer to a nuclear safe orbit at the end of the mission, so as to render the over-all use of the nuclear power source, with a high probability of success, as safe as if it had been used in a nuclear-safe orbit"(Principle 3, par 4). If the transfer to an NSO fails, provisions must be made to employ either an additional transfer technique or an "in-space recovery system ... as soon as technology permits". These alternative schemes must have the same probability of success as the original transfer system (Principle 3, par 5).

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457 Principle 3, par 2 of the NPS Principles, supra, note 455, states:

> States launching space objects with nuclear power sources on board into orbits around the Earth shall make every endeavour to use a nuclear-safe orbit, i.e., an orbit that gives sufficient time for radioactive materials to decay to an acceptable level in space after the end of a mission. To this end, the use of such an orbit shall in all circumstances ensure that the nuclear power source will remain in outer space at least 300 years in the case of a reactor, and at least 10 times the half life of the isotope or isotopes used in the case of a radio-isotope reactor.

The scope of the concept of NSO is meant "also to apply to orbits around other celestial bodies", in conformity with the Outer Space Treaty; UN GAOR, COPUOS, Twenty-Sixth Session of the Legal Sub-Committee, A/AC.105/C.2/SR.452 (Canada, 19 March 1987) par 35. Presumably then, the concept applies to orbits around the Moon as well.

If NPS is a necessary space technology,[458] establishment of NSOs as a means of isolating satellites with NPS on board is a laudable attempt to reduce the probability that a collision releasing radioactive space refuse will occur. However, this proposed solution could prove to be meaningless: (1) depending on the number, location and population of NSOs, collision probabilities could be as great or greater than those which would exist without NSOs;[459] (2) determining numerical, location and population variables should be left to an internationally-approved body of scientific experts, which does not yet exist;[460] (3) lowering the risk of creating radioactive space refuse is not enhanced either by the failure to make mandatory the use of NSOs during missions or reliance on yet-to-be-determined transfer techniques and in-space recovery systems; (4) "orbiting an in-space recovery system [would entail] a significant increase in energy needs and in

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458 It has been proposed that all space objects with NPS on board be excluded from outer space; UN GAOR, COPUOS, **Twenty-Sixth Session of the Legal Sub-Committee**, A/AC.105/C.2/SR.456 (Czechoslovakia, 23 March 1987) par 11.

459 Eg, of about 50 radioactive space-based NPS, more than 35 of them are found in altitudes between 900 and 1,000 km; N.L. Johnson, "Nuclear Power Supplies in Orbit" (1986), 2 **Space Policy** 223 at 226.

460 For a proposal for such a body, see Young, supra, note 62 at 326-28. The Scientific and Technical Sub-Committee of COPUOS has been requested to discuss the issue of establishing limits on the amounts of radioactive material carried by a single space object and the total amount of radioactive material in orbit at one time; UN GAOR, COPUOS, **Twenty-Sixth Session of the Legal Sub-Committee**, A/AC.105/C.2/SR.452 (Sweden, 19 March 1987) par 43.

general would create further difficulties",[461] and (5) outstanding issues, such as whether NSOs are solely for space objects with NPS[462] and how waste materials from NPS used as fuel in space objects will be disposed of[463], remain unresolved.

Perhaps these shortcomings will be addressed as the number and duration of manned space activities increases. The Scientific and Technical Sub-Committee of COPUOS has noted that nuclear safety should be ensured for all phases of a mission and that consideration should be given to "possible additional safety criteria [which] might be necessary to prevent, or cope with, events other than unplanned re-entry into the atmosphere alone"[464].

(iii) Space Refuse per se

It was recognized in COPUOS by 1981 that the increase in space activities would affect the state of the environment in

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[461] UN GAOR, COPUOS, **Twenty-Sixth Session of the Legal Sub-Committee**, A/AC.105/C.2/SR.460 (Czechoslovakia, 25 March 1987) par 11.

[462] UN GAOR, COPUOS, **Twenty-Fifth Session of the Legal Sub-Committee**, A/AC.105/C.2/SR.444 (Venezuela, 9 April 1986) par 22.

[463] Ibid., Algeria at par 30.

[464] UN GAOR, COPUOS, **Report of the Scientific and Technical Sub-Committee on the Work of Its Twenty-Fourth Session**, A/AC.105/383 (3 March 1987) par 59.

general.[465] The idea that space refuse posed a hazard to other regions of the near-Earth environment, such as LEO and GTO, was initiated at UNISPACE 82. To minimize the probability of collision between active space objects and space refuse, it was recommended that detailed studies be undertaken to provide the basis for appropriate regulatory measures, such as minimizing space refuse and removing inactive satellites by means of disposal orbits, controlled Earth re-entry or manned missions.[466] Further awareness that the space refuse problem extended beyond GEO is indicated by the inaugural appearance in 1983 of the theme of minimization and removal of space refuse from all of outer space in an on-going COPUOS study of GEO begun in 1977.[467]

The International Astronautical Federation (IAF)[468]

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465 UN GAOR, COPUOS, **Report of the Scientific and Technical Sub-Committee on the Work of Its Eighteenth Session**, A/AC.105/287 (13 February 1981) par 55.

466 UNISPACE 82 report, supra, note 445, par 289.

467 UN GAOR, COPUOS, **Physical Nature and Technical Attributes of the Geostationary Orbit**, A/AC.105/203/Add.4 (18 May 1983) par 37 [hereafter 1983 Physical Nature report]. This document represents the fourth update of the study. The first edition is UN GAOR, COPUOS, **Physical Nature and Technical Attributes of the Geostationary Orbit**, A/AC.105/203 (29 August 1977) [hereafter 1977 Physical Nature report]. A fifth revision is expected in 1988.

468 The IAF is a non-governmental association of national societies, institutions and bodies. Its purpose is to encourage the development of astronautics, to ensure widespread dissemination of scientific and technical information related to space and to encourage astronautical research; R. Chipman (ed.), **The World in Space: A Survey of Space Activities and Issues. Prepared for UNISPACE 82** (NJ: Prentice-Hall, 1982) 661.

recognized in a 1984 study that space refuse was a "particularly serious" and "real" problem in LEO and that international action was "imperative" in order to resolve the problem.[469] The IAF study stated that there was an "immediate need" for international research and policy development in the area[470] and recommended that the UN would be fulfilling a most important function if it were to initiate the development of policy and agreements on space refuse through international conferences[471]. Areas for action included a broad range of activities for minimizing the quantity of space refuse injected into and created in orbit, developing removal systems and increasing the data base on the space refuse environment.[472] The IAF also noted that the International Institute of Space Law (IISL) would initiate studies for defining the legal issues raised by space refuse, if so requested.[473]

Despite these efforts, it was not until 1987 that the UNISPACE 82 recommendations[474] were acted on by COPUOS.

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469 UN GAOR, COPUOS, Implications to International Co-operation of Large-scale Space Systems, A/AC.105/349 (7 December 1984) 19 [hereafter Space Systems].

470 Ibid., at 19-20.

471 Ibid., at 26.

472 Ibid., at 25-26. These recommendations are taken from AIAA, supra, note 418 at 370-71.

473 Ibid., at 26. The IISL is the legal arm of the IAF and studies legal problems arising from space activities; Chipman, supra, note 468 at 666.

474 Supra, text accompanying note 445.

Although their implementation was not considered urgent,[475] the Scientific and Technical Sub-Committee of COPUOS recommended that COSPAR and the IAF be invited to undertake a study of the environmental effects of space activities, "with particular emphasis on space debris"[476]. This recommendation was approved by COPUOS[477] and endorsed by the UNGA[478].

On 6 January 1988, COSPAR presented its preliminary report, noting that a comprehensive document would be submitted to COPUOS by the end of 1988.[479] The status report states that space refuse is recognized as a potential hazard and is a serious problem "even in geostationary orbit".[480] Its conclusion is clear and to the point: "Action on an international scale is obviously needed to deal with the global issue of space debris".[481]

Parallelling this increasing awareness of the importance of the space refuse issue, the Legal Sub-Committee of COPUOS

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475 UN GAOR, COPUOS, **Report of the Scientific and Technical Sub-Committee on the Work of Its Twenty-Fourth Session**, A/AC.105/383 (3 March 1987) par 19.

476 Ibid., Annex II, par 13(d).

477 UN GAOR, **Report of the Committee on the Peaceful Uses of Outer Space**, Supplement 20 (4/42/20) 10 July 1987, par 27.

478 **International Co-operation in the Peaceful Uses of Outer Space**, UNGA Res. 42/68 (2 December 1987).

479 UN GAOR, COPUOS, **Space Debris[:] A Status Report Submitted by the Committee on Space Research**, A/AC.105/403 (6 January 1988) 2-3.

480 Ibid., at 1 and 4.

481 Ibid., at 5.

has been searching for a new agenda item. It is submitted that the question of space refuse would be an ideal addition to the agenda, for three reasons.

First, it has been noted in COPUOS that increased pollution of outer space resulting from the proliferation of space refuse and the increase in NPS is creating a global hazard.[482] Moreover, the Swedish delegation has suggested that the topic of the outer space environment, including the question of space refuse, deserves to be examined by COPUOS and its two sub-committees.[483] If the issue is placed on the agenda of the Legal Sub-Committee, the IISL of the IAF is prepared to offer any assistance it could at the study level.[484]

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[482] UN GAOR, **Thirtieth Session of the Committee on the Peaceful Uses of Outer Space**, A/AC.105/SR.294 (Pakistan, 4 June 1987) par 18. Unofficially, the Soviet Union has supported the position that space refuse poses a hazard to the outer space environment. In a statement in COPUOS, omitted from the official records, the USSR representative stated that the increasing number of objects in outer space "would lead to questions on how to deal with the associated legal problems. The space environment must be dealt with immediately, rather than leaving it until late in the day as had happened with the earth's environment"; UN Press Release, "Outer Space Committee Considers Agenda of Legal Sub-Committee", OS/1259 (11 June 1986) 3.

[483] UN GAOR, **Twenty-Ninth Session of the Committee on the Peaceful Uses of Outer Space**, A/AC.105/SR.280 (1 July 1986) par 42 [French original, translation by the author].

[484] UN GAOR, COPUOS, **Twenty-Sixth Session of the Legal Sub-Committee**, A/AC.105/C.2/SR.454 (IAF Observer, 18 March 1987) par 22. The question of space refuse was discussed by the IAF in 1986 and 1987. See, eg, IISL session on legal aspects of outer space environmental problems in (1987), 30 **Colloquium Law of Outer Space** (publication forthcoming).

Second, the issue of space refuse and its regulation meets the criteria proposed for the new agenda item: it will promote respect for the fundamental principles of space law as laid down in the Outer Space Treaty;[485] it is suitable for the elaboration of legal principles;[486] it will advance legal questions regarding the peaceful uses of outer space;[487] it is practical, relevant and important in itself;[488] it has a reasonable chance of consensus;[489] it is within the scope of

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485 UN GAOR, COPUOS, **Twenty-Sixth Session of the Legal Sub-Committee**, A/AC.105/SR.475 (Canada, 1 April 1987) par 1 and UN GAOR, **Thirtieth Session of the Committee on the Peaceful Uses of Outer Space**, A/AC.105/SR.297 (Netherlands, 16 June 1987) par 64.

486 UN GAOR, **Twenty-Ninth Session of the Committee on the Peaceful Uses of Outer Space**, A/AC.105/SR.286 (Australia, 11 June 1986) par 6.

487 UN GAOR, **Twenty-Ninth Session of the Committee on the Peaceful Uses of Outer Space**: A/AC.105/SR.290 (Canada, 12 June 1986) par 1, A/AC.105/SR.290 (US, 12 June 1986) par 20 and A/AC.105/SR.291 (China, 13 June 1986) par 27; UN GAOR, COPUOS, **Twenty-Sixth Session of the Legal Sub-Committee**: A/AC.105/C.2/SR.454 (US, 18 March 1987) par 14 and A/AC.105/C.2/SR.471 (UK, 1 April 1987) par 8, and UN GAOR, **Thirtieth Session of the Committee on the Peaceful Uses of Outer Space** A/AC.105/SR.294 (Sweden, 4 June 1987) par 29.

488 UN GAOR, **Twenty-Ninth Session of the Committee on the Peaceful Uses of Outer Space**, A/AC.105/SR.291 (China, 13 June 1986) par 27; UN GAOR, **1986 Report of the Committee on the Peaceful Uses of Outer Space**, Supplement No. 20 (A/41/20) par 85; UN GAOR, COPUOS, **Twenty-Sixth Session of the Legal Sub-Committee**: A/AC.105/C.2/SR.454 (US, 18 March 1987) par 14, A/AC.105/C.2/SR.471 (UK, 1 April 1987) par 8 and A/AC.105/C.2/SR.475 (Canada, 9 April 1987) par 1, and UN GAOR, **Thirtieth Session of the Committee on the Peaceful Uses of Outer Space**: A/AC.105/SR.294 (Sweden, 4 June 1987) par 29 and A/AC.105/SR.297 (Netherlands, 16 June 1987) par 64.

489 UN GAOR, **Twenty-Ninth Session of the Committee on the Peaceful Uses of Outer Space**, A/AC.105/SR.292 (US, 13 June 1986) par 6; UN GAOR, COPUOS, **Twenty-Sixth Session of the**

the Legal Sub-Committee mandate,[490] and it is precise enough to avoid deep differences of opinion on how the item should be handled, thereby permitting legal work to be undertaken[491].

Third, the topic of space refuse has some connection with each of the five proposals suggested as options for the new agenda item: (i) strengthening the application of the Registration Convention;[492] (ii) State co-operation in event of an accident or an emergency on board a manned space object;[493] (iii) drafting a specific instrument devoted to manned space activities;[494] (iv) access of States to the

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Legal Sub-Committee: A/AC.105/C.2/SR.454 (US, 18 March 1987) par 14, A/AC.105/C.2/SR.471 (UK, 1 April 1987) par 8 and A/AC.105/C.2/SR.475 (Canada, 9 April 1987) par 1, and UN GAOR, **Thirtieth Session of the Committee on the Peaceful Uses of Outer Space:** A/AC.105/SR.294 (Sweden, 4 June 1987) par 29 and A/AC.105/SR.297 (Netherlands, 16 June 1987) par 64.

490 UN GAOR, COPUOS, **Twenty-Sixth Session of the Legal Sub-Committee**, A/AC.105/C.2/SR.454 (US, 18 March 1987) par 14.

491 UN GAOR, **Thirtieth Session of the Committee on the Peaceful Uses of Outer Space:** A/AC.105/SR.294 (Sweden, 4 June 1987) par 29 and A/AC.105/SR.297 (Netherlands, 16 June 1987) par 64.

492 Proposed by Sweden in 1986 and 1987; see, **eg**, UN GAOR, COPUOS, **Twenty-Sixth Session of the Legal Sub-Committee**, A/AC.105/C.2/SR.471 (1 April 1987) pars 2-7.

493 Proposed by the UK in 1986 and 1987; see, **eg**, **ibid.**, pars 9-10. This suggestion was supported by the United States; **ibid.**, par 12.

494 UN GAOR, COPUOS, **Twenty-Sixth Session of the Legal Sub-Committee**, A/AC.105/C.2/SR. 472 (USSR, 31 March 1987) par 2.

benefits of exploration and use of outer space,[495] and (v) legal aspects of the human presence in outer space, a combination of proposals (ii)-(iv)[496].

If the issue of space refuse is not chosen as the new agenda item, then it should be accorded serious consideration as an element of the topic ultimately selected.

(b) World Administrative Radio Conference (WARC) ORB-85/88

The rules of the ITU Convention and the Radio Regulations are generally devoted to transmitters and receivers on board space objects rather than the space objects themselves. Strictly speaking then, rules regulating space refuse may be considered ultra vires the ITU and its WARC on the Use of the Geostationary-Satellite Orbit and the Planning of Space Services Utilizing It (ORB-85/88).[497] Nevertheless, the ITU was requested to address at ORB-85 the issues of removal of

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495 Proposed by the Group of 77 in 1986; UN GAOR, Twenty-Ninth Session of the Committee on the Peaceful Uses of Outer Space, A/AC.105/SR.291 (Yugoslavia, 13 June 1986) pars 14-15. This suggestion was supported by Kenya, ibid., par 20; Iraq, id.; Czechoslovakia, ibid., par 23, and the Soviet Union, UN GAOR, COPUOS, Twenty-Sixth Session of the Legal Sub-Committee, A/AC.105/C.2/SR.472 (USSR, 31 March 1987) par 3.

496 UN GAOR, COPUOS, Twenty-Sixth Session of the Legal Sub-Committee, A/AC.105/C.2/SR.474 (Czechoslovakia, 6 April 1987) par 16.

497 Perek, supra, note 92 at 33 and 36. The first session of WARC ORB-85/88 was held in Geneva, August-September 1985. The second session, ORB-88, is scheduled to begin 29 August 1988 in Geneva and continue for more than five weeks; see agenda for ORB-88, ITU Doc. Administrative Council Res. 953 (27 June 1986).

inactive satellites from GEO and minimization of space refuse "in and near" GEO.[498]

Four States raised the space refuse issue during ORB-85. Kenya, repeating the proposal made in COPUOS by the equatorial States in 1984,[499] suggested that the objective of Article 33 of the ITU Convention[500] could not be met unless, **inter alia**, States and international organizations took the "necessary action to remove" their inactive satellites from GEO.[501] Algeria proposed that satellites "should ... leave" GEO when they are no longer in use, in order to "clean up" the orbit and to ensure access to it.[502] Iraq recommended that "the removal of dead satellites" from GEO be mandatory and, on a broader note, proposed that the ITU should undertake a study of the legal and financial aspects of collisions in GEO, in co-operation with "specialized committees of the United Nations dealing with space international law".[503]

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[498] See, eg, Perek, ibid., at 36-37; UN GAOR, COPUOS, **Twenty-Fifth Session of the Legal Sub-Committee**, A/AC.105/C.2/SR.446 (Sweden, 22 April 1986) par 34, and UN GAOR, COPUOS, **Twenty-Sixth Session of the Legal Sub-Committee**, A/AC.105/C.2/SR.466 (Sweden, 30 March 1987) par 5.

[499] Supra, note 450.

[500] Supra, note 449.

[501] **Kenya - Proposals for Work of the Conference**, ITU Doc. WARC ORB-85/20-E (24 June 1985) 4-5.

[502] **Algeria - Proposals for Work of the Conference**, ITU Doc. WARC ORB-85/75-E (8 August 1985) 4.

[503] **Iraq - Proposals for Work of the Conference**, ITU Doc. WARC ORB-85/87-E (9 August 1985) 5.

Only a proposal put forward by the United Kingdom received further deliberation during the ORB-85 session. The UK stated that the regulatory régime of GEO would be improved by minimizing "the risks of harmful interference to or from space services" using GEO.[504] Citing collisions with space refuse and blockage of radio signals by space refuse as causes of such interference, the UK put forward a recommendation urging satellite operators "to ensure that at the end of their useful lives [satellites] will present no residual sources of interference to other satellites in orbit".[505] This recommendation took into consideration two operational and economic factors connected with satellite removal; namely, that the quantity of propellant necessary for removing a satellite from GEO "could significantly reduce" a satellite's operational lifetime, and that a satellite which had completed its prime functions could be used for other purposes in GEO[506] or limited, temporary operational services in other orbits.[507]

The UK recommendation laid the foundation for a draft proposal for the effective use of GEO. In order to increase the capacity of GEO, it was advised that the International Radio Consultative Committee (CCIR) be urged to study the

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504 United Kingdom - Proposals for Work of the Conference, ITU Doc. WARC ORB-85/18-E (13 June 1985) 15.

505 Ibid., at 15-16.

506 See also, infra, text accompanying note 524.

507 UK Conference Proposals, supra, note 504 at 15.

issue of physical interference caused by space refuse, the findings of which could be reviewed at ORB-88.[508] Further study was urged, rather than a resolution or recommendation, on three grounds: the risk of physical interference was perceived to be very low; removal had economic implications,[509] and "most delegates realized that it was too soon to adopt any specific provisions because so many factors were unknown"[510]. Consequently, WARC ORB-85 requested that the CCIR undertake a study on physical interference resulting from

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508 The proposal, as expressed in Second Report of Working Group 4C to Committee 4 - Principles of Effective Use of Orbit and Spectrum by Fixed-Satellite Services, ITU Doc. WARC ORB-85/234(Rev.1)-E (5 September 1985) 13, states:

> 11. Sources of physical interference
>
> 11.1 In the geostationary-satellite orbit there is a risk of collision with active spacecraft and blockage of beams of operational satellites due to the presence of uncontrolled man-made objects. At present, the probability of such physical interference is very low, though the number of satellites is expected to increase over time. It is advisable therefore, to urge the CCIR to develop in the intersessional period a better understanding of this physical interference process leading to:
>
> -- an identification of relevant factors of what is thought at present to be a theoretical problem;
> -- an evaluation of the risks that this phenomenon could present in the future, and
> -- a recommendation for a solution to the problem should the study results justify further action.
>
> 11.2 The second session of WARC-ORB is invited to review the progress of these CCIR studies.

509 See, supra, text accompanying notes 506-507.

510 M.L. Smith, "Space Law/Space WARC: An Analysis of the Space Law Issues Raised at the 1985 ITU World Administrative Conference on the Geostationary Orbit" (1986), 8 Houston J Int'l L 227 at 244.

collisions with and blockages by space refuse.[511] The CCIR study has now been completed and submitted to WARC ORB-88 for its consideration.[512]

Thus, for the first time, the ITU has a specific mandate to investigate questions relating to space refuse and its implications for GEO and the space services utilizing it. Although the terms of reference of the CCIR study are limited in scope, it could result in concrete policy statements or even new Radio Regulations at ORB-88. More significantly, the combination of the ITU study and the COSPAR comprehensive report[513] could signal the beginning of efforts to develop an international regulatory régime for space refuse, encompassing all near-Earth space and taking into account the distinguishing features of each region of outer space.

(c) European Space Agency (ESA)

ESA is addressing three issues related to space refuse: possible congestion in GEO, the risk to "active space vehicles" in LEO and the risk ensuing from re-entry of space

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511 See Report to the Second Session of the Conference (Geneva: ITU, 1985) 31.

512 International Radio Consultative Committee, Report to the Second Session of the World Administrative Conference on the Use of the Geostationary-Satellite Orbit and the Planning of the Space Services Utilizing It (WARC-ORB(2)) (Geneva: ITU, 1988) 70.

513 See, supra, text accompanying note 479.

refuse into the Earth's atmosphere.[514] In addition to convening a workshop on the latter topic,[515] ESA established a working group in 1987 to study "all aspects of space debris which may have a detrimental effect on activities on ground and in space".[516]

To date, ESA has pursued a policy of removing spacecraft from GEO by the process of de-orbiting to a higher altitude (boosting).[517] The first ESA satellite to be boosted was Geos-2, which was placed in a near-circular orbit about 260-270 km above GEO,[518] an altitude somewhat less than planned[519]. Removal by boosting was considered the "only practical means of maintaining control of the situation".[520]

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[514] Personal correspondence with K. Barbance, International Affairs, ESA, 31 July 1987.

[515] European Space Agency, **Re-entry of Space Debris. Proceedings of an ESA Workshop, European Operations Centre, Darmstadt, FRG, 24-25 September 1985** (Paris: ESA Publications, 1986).

[516] Barbance correspondence, supra, note 514. A report on technical aspects as well as possible preventative measures and their financial implications is expected in Spring 1988.

[517] P. Beech et al., "The De-Orbiting of Geos-2" (1984), 38 **ESA Bulletin** 86 at 86 and "ESA Frees a Location on the Geostationary Orbit" (March 1984), **ESA Newsletter** 3. Braking is the term for de-orbiting a spacecraft to a lower altitude.

[518] Beech et al., ibid., at 89.

[519] "ESA Frees a Location on the Geostationary Orbit" (March 1984), **ESA Newsletter** 3.

[520] Id. Removal by braking could possibly result in collisions with objects in the GTO; "ESA is a Good Neighbour", **FLIGHT International** (10 March 1984) 629.

(d) International Telecommunications Satellite Organization (INTELSAT)

INTELSAT has adopted a general policy of using the remaining fuel on board satellites in GEO for boosting, at which time they are deactivated.[521] The boosting procedure is used to minimize problems of interference caused by the risks of collision and radiation, and to simplify administrative and maintenance operations.[522]

INTELSAT began de-orbiting satellites in December 1979, when the INTELSAT III (F-3) was pushed between 4,000-5,000 km beyond GEO.[523] Since some satellites may still perform useful functions after they have outlived their operational lifetime, INTELSAT created in 1982 a new functional category for satellite operations planning, the retired satellite.[524] This

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521 Personal correspondence with Kenneth Gross, INTELSAT, 14 July 1987. INTELSAT is a global telecommunication system providing, on a non-discriminatory basis, public telecommunication services to all countries. For a detailed analysis of INTELSAT, see N.M. Matte, Aerospace Law: Telecommunication Satellites (Toronto: Butterworths, 1982) 108-141.

522 Disposition of Obsolete INTELSAT Satellites, INTELSAT Doc. BG-27-23E W/3/77 (7 March 1977) 1-2.

523 "A Satellite's Passing" (1980), 1 intellink 3. At that altitude, INTELSAT III (F-3) will return to GEO in four to five million years; id. See also, Disposition of INTELSAT III (F-3), INTELSAT Doc. BG-40-38E W/12/79 (12 November 1979) 1.

524 Satellite Operations Planning, INTELSAT Doc. BG-51-51E L/6/82 (8 June 1982) Add.1 at 2. Other useful functions include communications testing, satellite subsystem testing, continued trend analysis, failure rate verification, verification of fuel accounting, TWTA lifetime, bearing behaviour before failure, bearing lifetime and final battery degradation; id.

new category effectively extends the period during which a satellite remains in GEO. Now, INTELSAT satellites are boosted and deactivated "when sufficient propellant remains to do so and no more valuable data can be obtained from those spacecraft".[525]

The international policy of boosting satellites has been followed by domestic satellite telecommunication organizations such as US Comsat and Telesat Canada.[526]

4. NATIONAL LAW AND POLICY

US legislation and policy cannot be overlooked in any discussion of space refuse, due to that nation's pervasive influence on the development of space technology and space law. In addition, the legal implications of the UK's Outer Space Act of 1986 for the space refuse issue will be discussed.

(a) United States

In the United States, three régimes regulate the use of outer space. Government use is administered by the National Aeronautics and Space Administration (NASA), commercial use by the Office of Commercial Space Transportation (OCST), Department of Transportation, and military use by the Department of

[525] INTELSAT Doc. BG-51-3E L/6/82 FINAL, par 122(e).

[526] For Telesat Canada, see CCIR report, supra, note 512, Annex A.2.15. See also, "Anik, Comsat Birds Removed from Service", Satellite Telecommunications (February 1985) 14 and "Phone-TV Satellite Replaced", The [Montreal] Gazette (27 November 1986) B5.

Defence (DoD). Law and policy regarding space refuse vary according to the régime.

(i) Government Use (NASA)

The National Aeronautics and Space Act of 1958 (NASAct)[527] governs civil space activities[528] and therefore influences commercial as well as government, but not military, space initiatives. NASA provisions for environmental protection are based on the National Environmental Policy Act (NEPA)[529] and its accompanying regulations[530]. "[A]ll NASA actions which may have an impact on the quality of the environment"[531] are subject to either an environmental assessment (EA)[532] or an environmental impact statement

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527 Publ L 85-568, 72 Stat 426; 42 USCS 2451 (1978 & Supp 1987).

528 Ibid., s. 101(b).

529 42 USCS 4321 (1978 & Supp 1987).

530 40 CFR 1508 (1986).

531 14 CFR 1216.301(b) (1988).

532 For a definition of EA, see 40 CFR 1508, s. 1508.9 (1986). Specific NASA actions normally requiring an EA include specific spacecraft development projects in space science and in space and terrestrial applications; specific experimental projects in space technology and energy technology applications; development and operation of new space transportation systems and advanced development of new space transportation and spacecraft systems, and reimbursable launches of non-NASA spacecraft or payloads; 14 CFR 1216.305(b) (1988).

(EIS)[533]. These requirements could act as regulatory mechanisms for space refuse.

Whether the NASA provisions for environmental protection extend to activities affecting the outer space environment turns on the definition of global commons. In international law, "global commons" includes those territories outside the territorial jurisdiction of any State, such as the high seas, the upper atmosphere, the oceans, Antarctica and outer space.[534] Whether outer space is included in the NASA mandate is uncertain, as a plain language reading of the legislation indicates that "global commons" extends only to oceans and the upper atmosphere,[535] to the exclusion of outer space.

It has been generally accepted among US agencies that major federal actions affecting the global commons should be

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533 For a definition of EIS, see 40 CFR 1508, s. 1508.11 (1986). An EIS is required where a NASA action is "expected to have a significant impact on the quality of the human environment". An EIS is necessary for R&D activities pertaining to the development and operation of new launch vehicles, space vehicles likely to release substantial amounts of foreign materials into Earth's atmosphere or into space, and certain nuclear propulsion and power generation systems; 14 CFR 1216.305(c) (1988). Although there is a lengthy list of exclusions from the EIS requirement, an EA may still be required if the NASA action may result in "significant environmental effects"; 14 CFR 1216.305(e) (1988).

534 Kiss, supra, note 125 at 1084.

535 14 CFR 1216.321(a) (1988) states in part:
[T]he Headquarters official shall analyze actions under his/her cognizance with due regard for the environmental affects abroad of such actions ... [and] shall consider whether such actions involve: (1) Potential environmental effects on the **global commons (ie, oceans and the upper atmosphere)** .... (emphasis added)

regulated.[536] In US documents discussing the issue of the extraterritorial application of NEPA, "global commons" is defined as "areas outside the jurisdiction of any country"[537] and as those regions "outside the jurisdiction of any nation (eg, the oceans or Antarctica)"[538]. Commentaries on this question have defined global commons as "not within the jurisdiction of any country",[539] "all areas outside the territorial jurisdiction of any nation, including the oceans, Antarctica, and probably the upper levels of the atmosphere and outer space"[540] and "geographical areas beyond the jurisdiction of any nation, such as the oceans and Antarctica, in which all nations have a common but nonpossessory interest"[541].

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536 J.D. Head, "Federal Agency Responsibility to Assess Extraterritorial Environmental Impacts" (1978), 14 Texas Int'l LJ 425 at 446.

537 "Memorandum on the Application of the EIS Requirement to Environmental Impacts Abroad of Major Federal Actions, September 24, 1976", 42 Fed Reg 61068, 61069 (1 December 1977). This document also defines "human environment" as including areas outside the jurisdiction of any country (eg, the high seas, the atmosphere); ibid., at 61068. (emphasis added)

538 "Environmental Effects Abroad of Major Federal Actions", Executive Order 12114, 44 Fed Reg 1957 (4 January 1979) s. 2-3(a) [hereafter Environmental Effects Abroad]. (emphasis added)

539 Head, supra, note 536 at 446.

540 C.G. Lehmann, "The International Application of the National Environmental Policy Act of 1969: A New Strategy" (1979), 4 Washington U LQ 1063 at 1080.

541 S.D. Sheridan, "The Extraterritorial Application of NEPA Under Executive Order 12,114" (1980), 13 Vanderbilt J Transnat'l L 173 at 175.

In all these instances, the inclusion of outer space as a global commons may be inferred, since outer space is beyond the territorial reach of any State[542]. As a major space power, the United States adheres to this definition. However, it is possible that the omission from the NASA regulations of outer space as a "global commons" was deliberate and not due to sloppy legislative drafting, in order to avoid regulating on matters concerning protection of the outer space environment.[543]

This decision would be consistent with the international obligations of the United States, since Article IX of the Outer Space Treaty provides for international protection of the outer space environment[544]. In addition, the United States would avoid setting any regulatory precedents. On the other hand, regulation of NASA activities affecting the global commons would also be consistent with US responsibilities for authorization and continual supervision of US space ac-

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542 Article II of the Outer Space Treaty, supra, note 14, states:

> Outer space, including the moon and other celestial bodies, is not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means.

543 Conversation with Prof. Stephen Gorove, Vice-President, IISL, 25 March 1988.

544 Supra, B/1(a)(vi).

tivities,[545] and could result in the avoidance of harmful contamination and potentially harmful interference[546].

While the present NASA scheme may not provide for protection of the outer space environment and hence for regulation of space refuse, NASA is addressing the space refuse issue at the policy level. In 1981, NASA initiated a space refuse policy, the focus of which is the Space Debris Assessment Program Plan. The purpose of this plan is "to define the activities and resources required over the next ten years to develop the necessary understanding of the man-made orbital debris environment ...".[547] Major elements of this plan are environment definition, hazard assessment, space object management and policy.[548]

Based on present information, implementation of the following policies are considered "prudent": design of payloads and rockets to remain intact until re-entry; development of techniques to monitor population growth of space refuse smaller than that currently detected; re-entry within a year of rocket stages used to transfer payloads from LEO to GEO, and a careful examination of space refuse implications

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545 Article VI, Outer Space Treaty, supra, note 14. See also, supra, A/4(b).

546 See, supra, text accompanying notes 358-376.

547 D.J. Kessler, "Earth Orbital Pollution" in E.G. Hargrove (ed.), Beyond Spaceship Earth: Environmental Ethics and the Solar System (San Francisco: Sierra Club Books, 1986) 47 at 60.

548 Ibid., at 60-61.

for the placement of "either large structures or a large number of objects in Earth orbit".[549] Any further policy would be held in abeyance until it is "clear what limits are required to minimize the increase in debris while maintaining a growing space program".[550]

Since effective control of space refuse is an international concern, it has been proposed that the United States support the development a space refuse policy "applicable at the international level ... [and] initiat[e] international proceedings to establish a world-wide policy to avoid unnecessary increases in the population of man-made objects".[551] As a point of departure, it has been recommended that the NASA ten-year plan "should be encouraged and supported at the international level".[552] It is envisioned that any space refuse policy developed by the United States would first be adopted by NASA; then extended to other US organizations with space activities, international customers of US space services and other States with independent space capabilities, and

549 Ibid., at 62.

550 Id.

551 D. Fielder, "Considerations for Policy on Man-Made Debris Propagation Control" in Kessler and Su, supra, note 208, 410 at 410-11. For discussions of US space refuse policy as of 1982, see D.S. Edgecombe, "Orbital Debris Policy Issues/Battelle Involvement and Some Personal Observations" in Kessler and Su, ibid., 402 at 406-409 and D. Fielder, "Policy Considerations" in Kessler and Su, ibid., at 437.

552 M.G. Wolfe, "Orbital Debris -- Current Issues as They Impact on an Expanding Manned Presence in Space" (1985), 28 Colloquium Law of Outer Space 260 at 265.

ultimately provide the basis for a global policy.[553] However, international regulation is perceived to be "inevitable" only "[w]hen the environment deteriorates to the point that satellites are obviously being disabled by impacts", since it is felt that any regulatory régime will stifle private enterprise and inhibit the growth of nations developing launch capabilities.[554]

In pursuit of a space refuse policy, the United States supports the international community initiatives of minimization and removal by de-orbiting. US satellites which have completed their useful lifetimes are removed from GEO, if such removal is practicable and feasible.[555] NASA recently considered proposing a new international standard under which all spent rocket stages would be subject to braking after payload placement.[556] A Space Debris Working Group has been formed to discuss the problem of space refuse and "ideas on

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553 Fielder, supra, note 551 at 418.

554 W.W. Mendell and D.J. Kessler, "Limits to Growth in Low Earth Orbit". Paper IAA-87-574, prepared for presentation at 38th Congress of the IAF, Brighton, 10-17 October 1987, at 5.

555 UN, UNISPACE 82, United States Initiatives at UNISPACE 82, A/CONF.101/INF.3 (19 August 1982) 6. See also, House Comm. on Foreign Affairs, 97th Cong., 2d Sess., Report on the Second UN Conference on the Peaceful Uses of Outer Space (UNISPACE 1982), August 9-21, 1982 (Comm. Print 1983) 22-23.

556 "Orbiting Junk Threatens Space Missions", The New York Times (4 August 1987) C1.

how the future situation might be improved".[557] At present, the working group is chaired by the Department of State and includes representatives from several US Executive Department agencies.[558]

(ii) Commercial Use (OCST)

Commercial space activities are governed by the Commercial Space Launch Act of 1984.[559] Any commercial entity wishing to launch a space vehicle with a payload on board must obtain a launch licence.[560] Three elements of the licensing process relate to protection of the outer space environment from space refuse: mission review information, payload determination and environmental impact assessment.

To obtain a launch licence, any commercial payload is subject to the mission review process.[561] Any commercial entity must, inter alia, "submit a flight plan and staging data sufficient for evaluating such factors as impacts of spent stages and debris issues"[562] and "identify any unique

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557 Schwetje, supra, note 408 at 6.

558 Id.

559 49 USCS Appx 2601 (1981 & Supp 1987). All US government activities, military or otherwise, are exempt from the provisions of the Act; ibid., s. 21 (c)(1).

560 51 Fed Reg 6870, 6881 (1986) (to be codified at 14 CFR 415.3(a)).

561 Ibid., at 6882 (to be codified at 14 CFR 415.21).

562 Ibid., at 6883 (to be codified at 14 CFR 415.25(b)).

hazards posed" arising from the "nature of the materials to be launched"[563].

A determination must be made as to whether launching a payload "would jeopardize ... any national security or foreign policy interest".[564] National security concerns could include preventing space refuse, the creation of which could possibly damage or interfere with US space activities in the most popular areas of LEO and GEO.[565] Foreign policy interests include obligations created by international agreements,[566] such as those under Article IX of the Outer Space Treaty[567]. Applicants must also provide an assessment of anticipated safety issues; a statement on the number of missions planned for payloads of the same or similar design; a description of payload design and construction; a description and definition

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563 Id., (to be codified at 14 CFR 415.25(c)).

564 Id., (to be codified at 14 CFR 415.27).

565 Schwetje, supra, note 2 at 263.

566 M.S. Straubel, "The Commercial Space Launch Act: The Regulation of Private Space Transportation" (1987), 52 J Air L & Comm 941 at 958.

567 Supra, note 14. These obligations include having due regard for the corresponding interests of other States in the peaceful use of outer space, avoiding harmful contamination of outer space and undertaking consultations if the United States believes that a commercial activity launched from a US facility could cause potentially harmful interference with another State's use of outer space; see, supra, B/1(a)(vi) and B/2(a).

of the proposed orbit, including altitude and inclination, and any other appropriate information.[568]

Environmental impacts of licensing commercial launch activities are addressed through either the OCST programmatic environmental assessment[569] or environmental impact statements for existing launch sites.[570] This documentation applies mainly to impacts on the environment of the launch site and surrounding area. However, the OCST, as a branch of a federal agency, is required to prepare an EIS for any major federal action significantly affecting outer space.[571] Exemptions from filing an EIS in this situation must be enacted by positive law.[572]

If the foregoing provisions do not provide sufficient protection to outer space environment from space refuse, the OCST has the regulatory power to implement further safeguards. The Office may request that applicants provide additional information if it determines that the required documentation does not "adequately address" the environmental effects of a

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[568] 51 Fed Reg 6870, 6883 (1986) (to be codified at 14 CFR 415.27 (a)-(e)).

[569] See Office of Commercial Space Transportation, **Programmatic Assessment of Commercial Expendable Launch Vehicle Programs** (Washington, DC: Department of Transportation, 1986).

[570] 51 Fed Reg 6870, 6883 (1986) (to be codified at 14 CFR 415.41).

[571] Environmental Effects abroad, **supra**, note 538, ss. 2-1, 2-3(a) and 2-4(b)(i).

[572] **Ibid.**, s. 2-5(d).

proposed launch activity.[573] It may also require that an applicant submit environmental information on "[o]ther factors" as determined by the Office.[574] Therefore, keeping in mind US proposals for a space refuse policy,[575] it could be argued that the environmental effects of a commercial space launch activity are not adequately addressed if that activity were to place in orbit a space object which would create space refuse with an overly lengthy lifetime or with the potential for increasing the amount of fragmentation debris or microparticulate matter, or which had not been designed and constructed so as to minimize creation of space refuse. Furthermore, to avoid the proliferation of space refuse, the OCST could require that every commercial launch entity indicate the steps it has taken to remove and minimize any space refuse which may be associated with its launch activity. These provisions would also reinforce and supplement OCST requirements for information on flight plan and staging data and on payload determinations regarding public health, safety, national security and foreign policy interests.[576]

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573 51 Fed Reg 6870, 6883 (1986) (to be codified at 14 CFR 415.41).

574 Id., (to be codified at 14 CFR 415.43(e)).

575 See, supra, text accompanying notes 548-558.

576 See, supra, text accompanying notes 562-568.

(iii) Military Use (DoD)

DoD as a whole, the US Air Force (USAF) and the Strategic Defense Initiative Organization (SDIO) are interested in the effects of space refuse on the military uses of outer space and have made contributions to the development of law and policy on space refuse.

DoD has been concerned about space refuse for some years.[577] When it became clear that space refuse had "the potential to restrict freedom of operations in certain regimes of space, the development of a global space debris policy [became] very desirable".[578] As a result, DoD commissioned a study in 1986 to determine whether the hazard potential from space refuse was sufficient to warrant adoption of a policy aimed at "reducing further contributions" to the space refuse environment and determining whether current technology would allow such a policy to be adopted.[579]

The study, carried out by the USAF Science Advisory Board (SAB), concluded that

> space debris represents a growing problem whose seriousness depends on future traffic and debris management. Even with careful control of future debris 'events', the level of debris ... will

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577 Wolfe and Temple, supra, note 408 at 1.

578 Ibid., at 4.

579 Id.

increase through fragmentation collisions of orbiting objects.[580]

The SAB recommended that uniform specification and design practices be adopted by US government, commercial and military users of space systems in order to minimize production of space refuse, and that the United States take the lead in establishing an international commission on space refuse.[581] This commission would "encourage cooperative measurements and exchange of data on the debris environment, ... implement agreed upon specifications and design practices for future space systems, and ... encourage international co-operation in dealing with hazardous events and warnings of potential collisions".[582]

Other SAB recommendations included (1) minimization of the "long-lived" space refuse produced by "ASAT and other weapons systems"; (2) development of system designs as well as "materials and surface treatments" to achieve this minimization, and (3) research on the "small debris environment in low earth orbit and its evolution", and on concepts and technologies needed "to protect Air Force space assets from

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580 "Special Report of the USAF Scientific Board Ad Hoc Committee on Current and Potential Technology to Protect Air Force Space Missions from Current and Future Debris (August 1987), cited in Schwetje, supra, note 408 at 5.

581 Id.

582 Draft of the Special Report of the USAF SAB, supra, note 580, at 7-8.

debris".[583] The report emphasized that it was "crucial" to make all organizations involved in space activities more aware of "the subject of space debris in general", in order to prevent further "degradation" of the outer space environment and to ensure the future use of outer space by the Air Force.[584]

As a result of this study, DoD adopted the following policy on space refuse:

> 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 the accumulation of space debris consistent with mission requirements.[585]

While this policy falls short of the SAB recommendations, it is significant on three counts. First, it serves as official notice that the major Western space power recognizes that space refuse poses an immediate problem for the use of outer space.[586] Second, it suggests that the issues raised by space refuse be addressed separately from and prior to other environmental concerns. Third, it ensures that the space refuse hazard will be taken into account in situations where a

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583 Ibid., at 8.

584 Id.

585 Department of Defense Space Policy (unclassified) 10 March 1987, at 3, cited in Reibel, supra, note 402 at 4. See also, Wolfe and Temple, supra, note 408 at 6.

586 The enactment of this policy signifies the first time that the issue of space refuse has been addressed in a major policy statement of the US government; Schwetje, supra, note 408 at 4.

military action is deemed not to affect significantly the outer space environment or is exempted from the EIS requirement.[587]

The policy is not without its shortcomings, however. Creation of further amounts of space refuse (through SDI tests, eg) would be justifiable, since "consistent military requirements" would give priority to possessing a space-based war capability over its environmental consequences.[588] In addition, while minimization is a praiseworthy goal, elimination of space refuse through design and operational changes would be more environmentally sound. It has been stated that elimination is neither realistically possible, due to technological limitations, nor necessary, since natural forces such as solar wind and atmospheric drag cleanse the outer space environment.[589] However, if the objective of R&D programmes were elimination of space refuse, the end result would likely yield greater reductions than those flowing from the more relaxed goal of minimization. Moreover, natural forces will not be able to cope with space refuse if it continues to increase at its present rate.[590]

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587 As a federal agency, DoD is also bound by Executive Order 12,114. See, supra, text accompanying note 571.

588 Reibel, supra, note 402 at 4.

589 Wolfe and Temple, supra, note 408 at 6.

590 See, supra, Chapter One: C/1(b), text accompanying note 237, and D/2(a), particularly text accompanying notes 357-359.

In addition to this policy statement, DoD is planning an experiment to help determine the impact of space refuse on manned and unmanned spacecraft. As part of a series of military man-in-space experiments on board the STS orbiter when its flights resume, military astronauts will "characterize debris belts by visual observation and compare their observations with those of remote sensors".[591]

The USAF policy on space refuse starts from the position that space refuse will become a problem only when larger space objects are in orbit.[592] Toward that end, spacecraft should be designed to prevent breakup due to collision; introduction of space refuse into outer space should be minimized, and removal of space refuse should be considered, but only if it is cost effective.[593] The USAF supports the need for an international solution to the space refuse problem, involving government, commercial and military users of outer space.[594]

At present, the USAF removes its satellites from GEO at the end of their useful lives and lessens the accumulation of space refuse in GEO by leaving in lower orbit spent rocket bodies used to place satellites in GEO.[595] In addition, USAF

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[591] Schwetje, supra, note 408 at 4.

[592] D. Hyland, "Air Force Orbital Position Management Policy" in Kessler and Su, supra, note 208, 393 at 393-94.

[593] Ibid., at 396.

[594] Ibid., at 397.

[595] Ibid., at 397-98.

Systems Command, Space Division pursues a minimization policy in the operation of its space systems. Insertion of additional refuse into space is limited through pre-launch and orbital phase planning and spacecraft design.[596]

Both the USAF and SDIO have carried out experiments which, in part, contribute to the environmental definition of space refuse. Aware of the problems of space refuse, one goal of the P78-1 (USAF) and Delta 180 (SDIO) tests of September 1985 was to create as little space refuse as possible. In so doing, these tests helped to develop and improve computer simulation models for predicting collision probabilities and fragment populations resulting from collisions, and for determining which future military test trajectories will create the least amount of space refuse.[597] In addition, the Delta 181 (SDIO) test of February 1988 collected data for investigation of the spaceglow phenomenon.[598]

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596 "Satellite Position Management", Space Division Regulation 55-1, cited in Schwetje, supra, note 408 at 4.

597 Schwetje, ibid., at 5-6.

598 "Delta 181 Mission Has Key SDI Flight Test Objectives", AvWk&SpTech (23 November 1987) 30 at 31 and "SDI Delta 181 Achieves Satellite Data Goals", AvWk&SpTech (15 February 1988) 14 at 16. Concerning spaceglow, see, supra, Chapter One: A/4(c).

(b) United Kingdom

The Outer Space Act 1986 received Royal Assent on 18 July 1986.[599] On entry into force, it will apply to all United Kingdom nationals carrying out space activities (ss. 1-2). The Act authorizes the Secretary of State to licence all such activities (s. 3(1)). Although space refuse is not specifically mentioned, several provisions could serve to limit its creation or shorten its lifetime.[600]

To be licenced, UK space activities must not jeopardize the safety of persons and property, must not impair national security and must be consistent with international obligations (s. 4(2)). Consequently, licences could be denied for those space activities which, by the creation of space refuse, pose a risk to persons and property of any State. Protecting national security interests could also include measures to eliminate space refuse.[601] Adherence to international obligations will not have a significant effect on the reduction of space refuse, due to inadequacies in the existing international legal régime.[602] Therefore, licensing regulations should be comprehensive enough to eliminate the legal

599 The Act is reproduced in (1986), 11 Annals Air & Space L 412.

600 The interpretations which follow are speculative, since regulations establishing and governing the licensing authority have not yet been promulgated.

601 See, supra, text accompanying notes 564-565.

602 See, supra, B/2.

lacunae at international law and to minimize, to the greatest extent feasible, the creation of space refuse. An assessment procedure such as that enacted under the US Commercial Space Launch Act could fulfill this objective.[603]

The licensing authority also has a discretionary power to attach conditions to any space activity licence it grants.[604] Failure to make this power mandatory severely limits what could be a forceful method for protecting the outer space environment from space refuse. However, the enumeration of several conditions in the statute itself may indicate that they are more likely to be attached on a regular basis, where necessary. Two of these conditions relate to space refuse.

A licensee may be required to conduct his space operations so as to "prevent the contamination" of outer space and "to avoid interference" with the peaceful activities of other users of outer space.[605] These conditions could have a greater force than their international counterparts found in Article IX of the Outer Space Treaty.[606] By omitting the term

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[603] Supra, B/4(a)(ii). The US commercial space regulatory procedure not only requires mission review information, payload determination and environmental impact assessment, but also contains a broad discretionary power to request any additional information deemed necessary to address the impact on the environment of launch activities.

[604] Outer Space Act 1986, supra, note 599, s. 5(1).

[605] Ibid., ss. 5(2)(e)(i) and (ii).

[606] Sentences 2 and 3 of Article IX of the Outer Space Treaty provide the basis for these conditions. For an analysis of these provisions, see the appropriate portions of B/1(a)(vi); for the legal effect of these principles, see the

"harmful", the strictly utilitarian régime of the sci-lab perception is avoided.[607] Accordingly, a prohibition could be placed on space activities which pose any risk of creating biological contamination caused by terrestrial organisms.[608] More significantly, space activities which could potentially cause any interference with the space activities of other States would be prohibited, whether or not the undertaking State reasonably believed its activity had the potential to cause interference.[609] Moreover, these prohibitions are enforceable. Contravention of a licensing condition may result in cessation of the offending activity or disposal of any space object in breach of that condition.[610]

The licensing authority may also prescribe the method to be used for "disposal of the payload in outer space on the termination of operations" and require that the licensee give notice of final disposition "as soon as practicable".[611] If international precedent is any indication, satellites in GEO

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relevant portions of B/2(a).

607 Supra, B/1(a)(i).

608 Cf, sentence 2 of Article IX of the Outer Space Treaty, supra, text accompanying notes 365-370.

609 Cf, sentence 3 of Article IX of the Outer Space Treaty, supra, text accompanying notes 371-373. Presumably, an objective test for interference would be developed by the licensing authority.

610 Outer Space Act 1986, supra, note 599, ss. 8(1)(b) and 8(2).

611 Ibid., s. 5(2)(g).

will be boosted, while satellites in LEO will be braked to the Earth's atmosphere for disintegration. However, the licensing authority could give the term "disposal" the more environmentally sound meaning of "removal". According to this interpretation, all satellites, regardless of their location, would be eliminated from outer space, if technologically feasible, on completion of their useful functions.

Although the disposal condition refers solely to "the payload", an argument can be made that responsibility for payload disposal, under either interpretation, entails responsibility for disposal of any subsequent space refuse generated by that payload: Placement of the disposal obligation in the licence is adequate advance notification to the satellite operator of the duty to dispose. Therefore, the operator must ensure that disposal procedures begin as soon as possible after the useful lifetime of the payload has ended. Failure to carry out these procedures in a timely manner does not obviate the duty to dispose, unless all duly diligent and reasonable efforts are attempted and prove to be unsuccessful.

CONCLUSION

Space refuse poses a variety of hazards to the space activities of mankind and to the integrity of the outer space environment. Inactive payloads, operational debris, fragmentation debris or microparticulate matter could precipitate collisions and interference or could be used for military purposes in outer space. Exactly when space refuse will trigger an extraterrestrial tragedy is unknown, since the number, size and location of space refuse objects cannot be quantified at present with any great precision, due to the technological and operational limitations of space object detection. Without this parametric information, questions central to understanding space refuse behaviour cannot be answered. Consequently, suitable remedies cannot be developed.

However, this much is certain: Space refuse has already caused damage to active payloads and interfered with Earth-based activities. If present trends continue, it will not be safe to carry out activities in certain sectors of outer space. If the proliferation of space refuse is not brought under control soon, the probability of the occurrence of a space refuse risk event will steadily increase with the placement of each new object in outer space, especially in those regions occupied by large structures such as space stations.

The problems posed by space refuse have not received any direct consideration in international law, particularly in the five space law treaties which form the basis for the regulation of human activities in outer space and on the Moon and other celestial bodies. No attempts have been made to address the central issues which space refuse raises: questions of definition, jurisdiction and control, international responsibility, identification, and compensation for damage. Furthermore, any regulation of space refuse afforded by the principles of public international law now in place is by inference at best. In most instances, that inference is very weak; yet even if it were stronger, creation of substantial amounts of space refuse would be permissible due to the inadequacies of the existing legal régime. Some States and international organizations have begun to address these issues and to develop appropriate policies and laws. Although laudable, these efforts are not sufficient.

Due to the physical nature and legal status of the outer space environment, action on an international scale is necessary in order to deal efficiently and effectively with the legal and technical issues raised by space refuse. Until a unified global initiative is undertaken, any advances in reducing and eventually eliminating the risks posed by space refuse will be haphazard and therefore inadequate. The proposed legal régime which follows is offered in the spirit of international co-operation for the preservation of the outer space environment per se and for the peaceful use of outer space by all mankind.

The régime for effective control of space refuse is based on three guiding principles:

** International responsibility for protection of the outer space environment entails a global approach, not a State-centred one. Accordingly, each State has an interest in and a right to an outer space environment free of space refuse, a corresponding duty to protect that environment and an obligation to provide compensation for damage resulting from its breaches of that duty.

** Recognizing State preferences for certain locations in low-Earth orbit (LEO) due to the technical and economic advantages they afford, and considering that manned space activities in LEO are restricted to altitudes between 200 and 1,000 km, due to physical and biological factors, LEO may be considered a limited natural resource of vital importance for a variety of space activities. Therefore, like the geostationary orbit (GEO), activities taking place in LEO require co-ordination and planning to ensure that all mankind can make optimum use of this unique resource.

** The environmental approach, not the sci-lab perspective, provides the foundation for the regulatory system. Consequently, the objective of the régime is the total elimination of space refuse, rather than short-term protection of specific regions of outer space in order to satisfy the immediate needs of space-capable States.

To be effective, the régime must consist of general principles of international law for facilitating the regulation of space refuse, a regulatory plan for co-ordinating the control of space refuse and an organizational structure for implementing the plan.

General Principles

The general principles are intended to fill the major lacunae existing at present in the international law of outer space as it pertains to space refuse.

** Definition: Space refuse means those man-made objects in outer space deemed to be valueless, as evidenced by an absence of operational control, and includes inactive payloads, operational debris, fragmentation debris and microparticulate matter.

** Jurisdiction and control: Removal of space refuse is permissible without the consent of the State of registration of the space refuse object, if that State cannot or will not undertake or authorize its removal.

** International responsibility: All States are internationally responsible for the space refuse they create and shall provide compensation for any damage caused by their space refuse, according to the principle of **restitutio in integrum.**

** Registration 1. Launching States shall record in the United Nations register, as soon as technologically possible, information on the launching of all actual and potential space refuse objects, whether or not they are launched into Earth orbit or beyond, and shall provide any additional information necessary for assisting in the detection of these objects.

2. All space objects, including potential space refuse objects, shall be marked in order to best facilitate their prompt and accurate identification.

** Liability 1. The term "damage" includes damage caused by space refuse to the outer space environment per se, the Moon and other celestial bodies.

2. If a space refuse object is identifiable, the State launching that object shall be absolutely liable to pay compensation for any damage caused by that object to any active payload; if the space refuse object cannot be identified, a fund provided by all launching States shall pay compensation for any damage caused by that object, on the basis of absolute liability.

** Prohibitions 1. Military or other hostile uses of space refuse are prohibited.

2. Creation of space refuse for use as an environmental modification technique for peaceful purposes is prohibited.

Regulatory Plan

Space refuse may be controlled by preventing its creation, by removing it from outer space or by avoiding situations conducive to the occurrence of risk events. The regulatory plan stresses prevention as the primary method of control and accepts removal as an ancillary procedure necessitated by the technological realities of space activities, but rejects avoidance. Avoidance schemes, such as evasion manoeuvres and space traffic separation, should be phased out as soon as technologically feasible and their funding bases applied to research and development of space refuse prevention and removal techniques. Avoidance procedures only postpone the inevitable, carry with them economic and technical costs in excess of their benefits and are restricted in their effectiveness to avoidance of collisions between active payloads and trackable space refuse objects.

The regulatory plan sets out guidelines which are flexible enough to respond to the rapid pace of scientific and technological development, yet specific enough to indicate clearly the scope of permissible activities.

** States shall prevent the creation of all space refuse, where technologically feasible. Failure to adhere to this obligation shall be deemed to be a breach of the duty to carry out space activities with due regard for the corresponding interests of other States.

** States shall in good faith use their best technological efforts to develop operational procedures and technical design strategies to prevent space refuse creation.

1. Operational procedures could include (i) examination of all space activities for space refuse implications; (ii) limitation of weapons testing to altitudes at which the complete decay of space refuse would be ensured; (iii) removal

of active payloads on completion of their operational lifetimes, and all rocket stages, including those transferring payloads to GEO; (iv) selection of orbital parameters and launch windows so as to minimize the occurrence of space refuse risk events; (v) closer spacing of active payloads in GEO and reduction of its population through the use of antenna farms, and (vi) re-entry of one space object for every object launched.

2. Technical design strategies could include (i) controlled payload re-entry, multi-purpose spacecraft and reusable launch vehicles; (ii) space transportation systems free of litter and other ejecta; (iii) explosion reduction; (iv) paints, thermal coatings and binder agents which do not break down in outer space; (v) aluminum oxide-free fuels; (vi) recycling by manned spacecraft of waste products and gases, and (vii) computer modeling and simulation of space refuse populations.

** All space refuse shall be removed from outer space by planned and controlled re-entry, retrieval or disposal techniques, if all good faith efforts cannot prevent its creation. Natural decay mechanisms shall not be relied on for removal.

1. If recyclable, space refuse shall be subject to re-entry or retrieval. If suitable re-entry or retrieval technology does not exist, active payloads (eg, telecommunication

satellites) shall be placed in temporary storage orbits until the necessary technology is developed.

2. If unrecyclable due to economic or technological factors, space refuse shall be subject to manned or unmanned collection, followed by disposal via planned and controlled decay, solar furnaces or solar disposal. Disposal by solar system escape or placement in solar orbit is prohibited. Use of outer space for the disposal of any radioactive or other Earth-based wastes is prohibited.

3. Use of nuclear power sources (NPS) in outer space is prohibited, pending development of economically and technologically suitable alternatives. Until then, all NPS shall be designed for use and storage in nuclear safe orbits (NSO). NSOs shall contain only NPS and shall be regulated as to their number, orbital parameters and radioactive content. When NPS pose no risk of radioactive contamination, they shall be subject to removal.

4. All States undertaking space activities shall fund research and development of removal technologies in proportion to their creation of space refuse.

Organizational Structure

To be successful, the organizational structure for implementing the regulatory plan to control space refuse must reflect both the political and commercial realities of space activities. Since outer space is the common heritage of mankind, all States must have an opportunity to contribute to the development of the general policy and overall objectives of the organization. Since space activities are generally long term, capital intensive and highly dependent on advanced technologies, the organization must function as a sophisticated corporate enterprise.

The desired structure could be achieved by combining various elements of existing international organizations. As in the International Telecommunications Satellite Organization, policy could be developed by member States, while operation and management functions could be the responsibility of a board of directors drawn from the space agencies of member States. As in the International Telecommunication Union, an international committee of consulting experts could be relied on to provide the board with the most up-to-date scientific and technical information on space refuse. As in the International Civil Aviation Organization, technical annexes containing mandatory standards and recommended practices could be adopted by the board in consultation with the experts, in order to achieve uniformity in the regulation of space refuse.

While this structural model is proposed as a solution to the space refuse problem, it could also provide the foundation for a global international organization dedicated to the co-ordination of human activities in outer space. With such an organization, the necessary balance could be achieved between the exploration and use of outer space today and the protection of this shared universal resource for future generations.

APPENDIX I: ACRONYMS AND ABBREVIATIONS

AIAA	American Institute of Aeronautics and Astronautics
ALS	Advanced Launch System
ASAT	Antisatellite Weapons
CCIR	International Radio Consultative Committee
CERV	Crew Emergency Rescue Vehicle
CETEX	Committee on Contamination by Extraterrestrial Exploration
COPUOS	Committee on the Peaceful Uses of Outer Space
COSPAR	Committee on Space Research
COSPAR-CG	COSPAR Consultative Group on the Potentially Harmful Effects of Space Experiments
DoD	Department of Defense
EA	Environmental Assessment
EIS	Environmental Impact Statement
ELV	Expendable Launch Vehicle
ESA	European Space Agency
ETS	Experimental Test System of Lincoln Laboratory
EVA	Extravehicular Activity
GEO	Geostationary Orbit
GEODSS	Ground-based Electro-Optical Deep Space Surveillance System
GTO	Geosynchronous Transfer Orbit
HLV	Heavy Lift Vehicle

IAF	International Astronautical Federation
ICSU	International Committee of Scientific Unions
IFRB	International Frequency Registration Board
IISL	International Institute of Space Law
INTELSAT	International Telecommunications Satellite Organization
IRAS	Infrared Astronomical Satellite
ITU	International Telecommunication Union
IUS	Inertial Upper Stage
LEO	Low-Earth Orbit
MHV	Miniature Homing Vehicle
MIR	Soviet Space Station
NASA	National Aeronautics and Space Administration
NEPA	National Environmental Policy Act
NORAD	North American Aerospace Defense Command
NPS	Nuclear Power Source
NSO	Nuclear Safe Orbit
OCST	Office of Commercial Space Transportation
ORB-85/88	WARC on the Use of the Geostationary-Satellite Orbit and the Planning of Space Services Using It
OTV	Orbital Transfer Vehicle
PAM	Payload Assist Module
PARCS	Perimeter Acquisition and Attack Characterization System
SAB	USAF Scientific Advisory Board

SAFE	Satellite Fragmentation Test
SDI	Strategic Defense Initiative
SDIO	Strategic Defense Initiative Organization
Solar Max	Solar Maximum Mission Satellite
SRM	Solid-propellant Rocket Motor
SSC	Space Surveillance Center
STS	Space Transportation System
TDRS	Tracking and Data Relay Satellite
UK	United Kingdom
UN GAOR	United Nations, Official Records of the General Assembly
UNGA Res.	United Nations General Assembly Resolution
UNISPACE 82	Second United Nations Conference on the Exploration and Peaceful Uses of Outer Space
US	United States of America
USAF	United States Air Force
USISS	United States-initiated International Space Station
USSR	Union of Soviet Socialist Republics
WARC	World Administrative Radio Conference

APPENDIX II: SELECTED BIBLIOGRAPHY

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