Legal aspects of Active Debris Removal (ADR): regulation of ADR under international space law and the way forward for legal development

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2 General Overview of Space Debris and ADR

This chapter will address the question as to why is space debris a problem and what are the issues relating to governance of ADR that need legal answers from international space law. To answer this question, the chapter will be divided into three sections. Section 2.1 will present a general overview of what space debris is. Section 2.2 will introduce the problems caused by the proliferation of space debris and the need for ADR to address the debris problem. Section 2.3 will introduce the current status of ADR missions and identify four issues relating to the governance of ADR activities. Section 2.4 will provide the conclusion of this chapter.

2.1 Overview of the Space Debris Problem

Space debris is a by-product of human activities in outer space, which includes inactive satellites and defunct launch vehicle orbital stages, discarded hardware such as separation bolts, fragments created as a result of spacecraft or orbital stages explosions and collisions, and tiny flecks of paint released by thermal stress or small particle impacts.[1] Historically, the primary sources of space debris in Earth's orbits have been: (a) accidental and intentional break-ups which generate long-lived debris and (b) debris released intentionally during the operation of rockets and spacecraft.[2] In the future, collisions involving non-manoeuvrable rocket bodies and spacecraft are predicted to become the dominant source of new debris.[3] Currently, catastrophic collisions, which are collisions that lead to the fragmentation of massive objects in orbit, are expected to occur every 5 to 9 years.[4]

There is no internationally binding definition of space debris. The most widely accepted definition is the one contained in the IADC Space

1 NASA. Frequently Asked Questions on Orbital Debris. <https://orbitaldebris.jsc.nasa.gov/faq/>.

2 Section 1 "Background", Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space ("COPUOS Space Debris Mitigation Guidelines"), endorsed by COPUOS at its 50th session and contained in UN Doc. A/62/20, annex, and endorsed by the UN General Assembly in its resolution 62/217 of 22 December 2007.

3 IADC. (2022). IADC Statement on Active Debris Removal ("IADC ADR Statement"), IADC-22-02, p. 1.

4 Ibid. See also IADC. (2013). Stability of the Future LEO Environment – An IADC Comparison Study ("IADC Study of 2013"). IADC-12-08, Rev. 1, p. 1.

Debris Mitigation Guidelines and the COPUOS Space Debris Mitigation Guidelines.[5] Space debris is defined for the purpose of these non-binding instruments as "all human made objects including fragments and elements thereof, in Earth orbit or re-entering the atmosphere, that are non-functional".[6] The IADC Space Debris Mitigation Guidelines further specify that "[a] spacecraft that can no longer fulfil its intended mission is considered non-functional", and this does not include "[s]pacecraft in reserve or standby modes awaiting possible reactivation".[7] Therefore, a spare satellite placed in orbit is not to be regarded as space debris. This definition describes the three characteristics of space debris, namely artificial nature, absence of functionality, and location. More specifically: (i) the term "space debris" includes objects of all sizes that are the product of human space activities and not of natural origin; (ii) these objects are either never functional or eventually become non-functional; and (iii) these objects are situated in Earth orbit or are re-entering the atmosphere.[8] As space debris concerns objects orbiting the Earth, it is sometimes also referred to as "orbital debris", defined as "any human-made object in orbit about the Earth that no longer serves a useful function".[9]

While orbits around the Earth are currently the most heavily used areas in outer space, there are activities that go further beyond to the Moon and other celestial bodies, which have thereby left artificial remnants in these areas. With regard to lunar debris, due to the heterogeneous mass distribution of the Moon, lunar satellites can suffer from instability in their orbits, which will over time become so elliptical that they eventually hit the lunar surface.[10] When it comes to Martian debris, there have been around eighteen spacecraft missions operating in Martian orbit as of August 2023, of which seven are currently active.[11] Unlike objects in Earth's orbits that can

5 IADC. (2021). IADC Space Debris Mitigation Guidelines, Rev. 3, IADC-02-01. Sec. 1, COPUOS Space Debris Mitigation Guidelines. These two sets of space debris mitigation guidelines will be discussed in more detail in Chapter 4 Section 4.1.1.

6 Sec. 3.1, IADC Space Debris Mitigation Guidelines. Sec. 1, COPUOS Space Debris Mitigation Guidelines.

7 Sec. 3.2.1, IADC Space Debris Mitigation Guidelines.

8 Hobe, S. (2012). Environmental Protection in Outer Space: Where We Stand and What is Needed to Make Progress with regard to the Problem of Space Debris. *Indian Journal of Law and Technology*, *8*(1), p. 2.

9 NASA. (2021). Space Debris and Human Spacecraft. <https://www.nasa.gov/mission_pages/station/news/orbital_debris.html>.

10 Kottke, J. (2021). Apollo 11's Lunar Module Might Still Be Orbiting the Moon. <https://kottke.org/21/07/apollo-11s-lunar-module-might-still-be-orbiting-the-moon>.

11 See "List of Mars orbiters" <https://en.wikipedia.ahnu.cf/wiki/List_of_Mars_orbiters>. For a comprehensive list of missions to Mars see NASA. Historical Log | Missions – Mars Exploration. <https://mars.nasa.gov/mars-exploration/missions/historical-log/>.

be routinely tracked and catalogued, the position of inactive Martian probes "is not known, nor what happened to them after completion of operation". [12]

With the increase of human activities in areas beyond Earth's orbit, debris may in the future become an issue in these areas when the number of artificial satellites increases there. Indeed, NASA Standard 8719.14C already encourages operators "to limit the release of debris while in Moon or Mars orbit".[13] This indicates that the issue of debris is also considered for missions beyond Earth orbit. Meanwhile, to address the debris issue of other celestial bodies, the different orbital mechanisms between the Earth and other celestial bodies would need to be taken into account, such as the difference in their mass and gravitational force as well as the existence and thickness of the atmosphere. As a result, different debris mitigation strategies may need to be devised. As submitted by Weeden and Chow, these different orbital areas "would almost certainly require a different or tailored governance framework".[14]

While it is also necessary to protect the environment of outer space beyond Earth orbit, the proliferation of space debris surrounding the Earth is currently the most concerning issue to be tackled. These non-functional man-made objects reside in regions of space in which most space activities take place, including crewed spaceflights such as the International Space Station (ISS) and China's Tiangong Space Station, and they pose a threat to the safety of space missions.[15] In addition, the number of existing debris in Earth's orbits is currently far greater than that in orbits around the Moon and Mars, and States may not have to face the problem of debris remediation in the latter areas if they could avoid the repetition of history and take effective measures to limit the creation of debris there from the outset.[16] Moreover, the congestion caused by the growth of space debris in Earth orbit can hinder access to further areas, which makes the stability of the orbital environment also essential for deep space missions, including

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12 Suchantke, I., Letizia, F., Braun, V., & Krag, H. (2020). Space sustainability in Martian orbits — First insights in a technical and regulatory analysis. *Journal of Space Safety Engineering*, *7*(3), p. 440. For active satellites, their position in the Martian environment can be monitored through telemetry data. See Suchantke et al., ibid.

13 Sec. 4.3.1.1, NASA Standard 8719.14C, Process for Limiting Orbital Debris, approved 5 November 2021.

14 Weeden, B. C., & Chow, T. (2012). Taking a Common-Pool Resources Approach to Space Sustainability: A Framework and Potential Policies. *Space Policy*, *28*(3), p. 168.

15 Shadbolt, L. (2023). *Technical Study Space Debris*. HDI Global Specialty SE ("HDI Study of 2023"), p. 9.

16 According to the Indian Space Research Organisation (ISRO), as of July 2023, there are six active lunar orbiters. The operating agencies of these objects are undertaking effective coordination to avoid critical conjunctions in the Lunar orbit. See ISRO. (2023). Current Space Situation around the Moon – An Assessment. <https://www.isro.gov.in/Current_Space_Situation_around_Moon_Assessment.html>.

those to the Moon and Mars.[17] Therefore, space debris in orbit around the Earth is at present the primary concern of the international community, and this dissertation will thus focus on the removal of debris orbiting the Earth.

According to the estimation of ESA, as of 6 December 2023, there are about 36,500 space debris objects larger than 10 cm, 1 million space debris objects between 1 cm and 10 cm in size, and 130 million space debris objects from greater than 1 mm to 1 cm.[18] This indicates that there are far more smaller debris than larger ones.[19] Only those objects above a certain size threshold are currently trackable. Routine ground-based radar and optical measurements performed by space surveillance systems allow the tracking and cataloguing of objects larger than 5-10 cm in LEO and objects larger than 0.3-1.0 m in GEO.[20] A main source of information on space debris is the United States (US) Space Surveillance Network (SSN), which catalogues around 27,000 objects in Earth orbit as of 3 February 2023.[21] Trackable debris only accounts for a small proportion (less than 1%) of the total space debris population, while the vast majority of the space debris population is too small to be tracked or catalogued, and hence the orbital position and trajectory of these small objects cannot be accurately known or predicted.[22]

The problem of space debris is aggravating because the amount of space debris is growing every year and is expected to increase continuously in the future. According to a report published by the IADC in 2023:

> "The environmental evolution results identify that a doubling of the space debris population may occur within 25 years and an increase of 10 times over the longer term due to an increasing rate of catastrophic collisions. Critically, even in the case of no further launches into orbit, it is expected that collisions among existing space debris objects will lead to a further growth in space debris population."[23]

17 Choudhury, S. R. (2018). Space junk is a big problem and it's going to get worse. *CNBC*. <https://www.cnbc.com/2018/09/18/wef-tianjin-space-junk-is-a-big-problem-and-its-going-to-get-worse.html>.

18 ESA. (Last updated 6 December 2023). Space Debris by the Numbers. <https://www.esa.int/Space_Safety/Space_Debris/Space_debris_by_the_numbers>.

19 Liou, J.-C. (2013). Engineering and Technology Challenges for Active Debris Removal. *Progress in Propulsion Physics*, *4*, p. 740.

20 ESA. (last updated April 2021). Frequently Asked Questions on Space Debris. <https://www.esa.int/Space_Safety/Space_Debris/FAQ_Frequently_asked_questions>.

21 NASA Orbital Debris Program Office. (2023). Monthly Number of Objects in Earth Orbit by Object Type. *Orbital Debris Quarterly News*. *27*(1), p. 12. It should be noted that not all tracked objects are catalogued, which requires an object to be tagged to a specific launch event. Weeden, B. (2011). Overview of the Legal and Policy Challenges of Orbital Debris Removal. *Space Policy*, *27*(1), p. 41. As of December 2023, the US SSN tracks around 44,600 objects in total. The information of the tracked objects is available at: <https://www.space-track.org/auth/login>.

22 Shadbolt (2023), *supra* note 15, pp. 7-8.

23 IADC. (2023). IADC Report on the Status of the Space Debris Environment ("IADC Report of 2023"). IADC-23-01, p. 6.

The projection of the IADC shows that the current space debris situation is heading in the direction of the Kessler syndrome. Another issue related to the congestion in the orbital environment is the placement of constellations consisting of hundreds and thousands of satellites in Earth orbit for the purposes of communication and Earth observation. Since 2019, the number of satellites in LEO has grown rapidly due to the deployment of several mega-constellations in Earth orbit by private companies such as SpaceX and OneWeb.[24] This sudden rise marks the start of "New Space", representing "an era dominated by commercial space actors and mega-constellations".[25] Largely as a result of these constellations, the current launch traffic is around 10 times the level observed in 2000.[26] In particular, SpaceX has 4,519 Starlink satellites in orbit as of July 2023, and it plans to eventually launch as many as 42,000 satellites in the Starlink constellation.[27] It has been estimated that the satellites to be launched over the next five years will outnumber those launched globally over the entire history of spaceflight.[28] The significant growth of launch traffic increases the chances of collision with the existing objects in orbit and can thereby accelerate the Kessler syndrome. The growing congestion in the orbital environment means that space debris is becoming an ever-pressing issue to be solved.

2.2 Risks Posed by Space Debris

Space debris orbits around the Earth at a speed of approximately 28,000 km per hour.[29] In particular, the relative velocity between many objects that come close to each other in LEO is often on the order of 10 km/s, which is ten times faster than a rifle bullet.[30] At such speeds, even a small debris piece has the potential to cause significant damage. As explained in the COPUOS Space Debris Mitigation Guidelines, "[t]he implementation of space debris mitigation measures is recommended since some space debris has the potential to damage spacecraft, leading to loss of mission, or loss of life in the case of manned spacecraft."[31] In addition, "there is also the risk of damage on the ground, if debris survives Earth's atmospheric re-entry".[32]

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24 Shadbolt (2023), *supra* note 15, pp. 9-10.
25 Byers, M., & Boley, A. (2023). *Who Owns Outer Space? International Law, Astrophysics, and the Sustainable Development of Space.* Cambridge University Press, p. 54.
26 IADC (2023), *supra* note 23, p. 5.
27 Pultarova, T., & Howell, E. (3 August 2023). Starlink Satellites: Everything You Need to Know about the Controversial Internet Megaconstellation. <https://www.space.com/spacex-starlink-satellites.html>.
28 Krag, H. (2021). A Sustainable Use of Space. *Science*, *373*(6552), p. 259.
29 JAXA. (2023). Removal of Space Debris. <https://www.kenkai.jaxa.jp/eng/crd2/about/>.
30 Shadbolt (2023), *supra* note 15, p. 7.
31 Sec. 2, COPUOS Space Debris Mitigation Guidelines.
32 Sec. 1, ibid.

Accordingly, the risks posed by space debris can be classified as risks to satellites, to crewed spacecraft, and to the ground. On top of these risks, the continuous growth of space debris can also endanger the long-term sustainability of outer space activities. The following sections will introduce these risks.

2.2.1 Risks to Satellites

Debris of different sizes pose different levels of risk to space activities. Impact by debris larger than 10 cm can cause catastrophic break-ups, which may completely destroy the colliding spacecraft and generate hundreds and thousands of debris fragments, contributing to the run-away cascading Kessler syndrome.[33] A collision with space debris larger than 1 cm in size can pose a mission-ending threat to spacecraft.[34] A collision with debris larger than 1mm in size can lead to significant impact or loss of mission due to penetration of the fuel tank and other critical infrastructure.[35] As mentioned earlier, small debris objects are not trackable, and it is therefore not possible to warn about potential collisions with them. The only means to protect satellites from the impacts of small debris is to cover them with protective shields, which can significantly increase the survivability of satellites against debris up to 1 mm in size.[36] Hence, millimetre-sized debris objects pose the highest mission-ending risk to most operational spacecraft in LEO, for they are numerous in amount, unable to be tracked, and hard to be shielded against.[37]

Non-trackable debris is already suspected of being the cause of a number of spacecraft anomalies and failures, such as the Sentinel-1A debris collision in August 2016, where the solar panel of the satellite was likely struck by a 1 cm particle of debris. A collision with larger debris may likely lead to the fragmentation or disintegration of the satellite concerned, and a prominent example in this regard is the collision between Iridium 33 and Cosmos 2251 on 10 February 2009 at an altitude of 790 km, known as "the first accidental hypervelocity collision of two intact satellites" in orbit.[38] Iridium 33 was a 560 kg active communications satellite owned and operated by the US-based private company Iridium, and Cosmos 2251 was a decommissioned

33 ESA (2021), *supra* note 20.
34 NASA OIG. (2021). *NASA's Efforts to Mitigate the Risks Posed by Orbital Debris*. Report No. IG-21-011, p. 3.
35 Ibid.
36 JAXA (2023), *supra* note 29.
37 NASA (2021), *supra* note 9.
38 Johnson, N. (16 October 2009). The Collision of Iridium 33 and Cosmos 2251: The Shape of Things to Come. *Conference Paper at the 60th International Astronautical Congress (IAC)*, p. 2. <https://ntrs.nasa.gov/citations/20100002023>.

Russian satellite with a mass of approximately 900 kg.[39] The collision was unprecedented in terms of the amount of space debris created, for a total of 2370 fragments from the 2009 collision have been catalogued by the US SSN.[40] As such, the 2009 collision shows that the threat posed by space debris to operational satellites is not solely theoretical but indeed real.

Because the orbital environment is becoming increasingly crowded, it is important to reduce the risk of collisions. The US Combined Space Operations Center (CSpOC) alerts satellite operators of potential collisions involving objects 10 cm or greater in size.[41] ESA's Space Debris Office is in charge of providing debris alerting services for all ESA missions, as well as those of some partner and third-party missions.[42] After receiving a collision warning, satellite operators analyse the collision risk in more detail and if necessary, have their satellites perform collision avoidance manoeuvres (CAMs). According to ESA, each of its Earth-orbiting satellites conducts on average two CAMs per year.[43] The growing congestion in Earth orbit can lead to an increase in collision warnings and CAMs. These CAMs consume extra fuel and can interrupt mission operations. Hence, the space debris population should be properly controlled to reduce the need for CAMs.

2.2.2 Risks to Crewed Spacecraft

Similar to the risks posed to satellites, space debris can also threaten crewed space missions. Specifically, NASA considers space debris as "a major safety risk" to the ISS.[44] To deal with this risk, NASA has established a set of guidelines that define the operations to be taken according to the risk level, and a CAM will be conducted when the risk reaches a certain threshold.[45] As of May 2023, the ISS has conducted a total of 35 CAMs against tracked objects since 1999.[46]

Like satellites, the operation of CAMs for the ISS requires the awareness of the position and estimated trajectory of space debris, and therefore the

39 NASA Orbital Debris Program Office. (2009). Satellite Collision Leaves Significant Debris Clouds. *Orbital Debris Quarterly News*. *13*(2), pp. 1-2.

40 NASA Orbital Debris Program Office. (2021). Accidental Collision of YunHai 1-02. In *Orbital Debris Quarterly News*, *25*(4), p. 1. See also Masson-Zwaan, T. L. (2009), Space law and the satellite collision of 10 February 2009, *COSPAR's Information Bulletin: Space Research Today*, *174*, p. 7.

41 Dural, S., Tugcular, U., & Daser, B. (2021). General Collision Avoidance Maneuver Decision Algorithm. *Proceedings of 8th European Conference on Space Debris*, p. 1.

42 ESA (2021), *supra* note 20.

43 Ibid.

44 NASA Orbital Debris Program Office. (2020). International Space Station Maneuvers to Avoid Debris. *Orbital Debris Quarterly News*. *24*(3), p. 1.

45 Ibid.

46 NASA Orbital Debris Program Office. (2023). ISS Maneuvers Twice in a Week's Span to Avoid Potential Collisions. *Orbital Debris Quarterly News*. *27*(2), p. 1

ISS can only dodge trackable debris which is the size of 5-10 cm and larger. Shields may protect ISS from smaller debris, but they have limitations. The US modules of the ISS are equipped with protective shields effective against space debris of about 1 cm and smaller, while other non-US modules of the ISS are not as well protected.[47] As an example of the collision risk, in May 2021, a hole of approximately 5mm in diameter caused by space debris was noticed on one of the Canadarm2's boom segments during a routine inspection.[48] Fortunately, the performance of Canadarm2 remains unaffected, and the robotic arm continues to conduct its planned operations.[49] Yet, the fact that no significant damage is caused may just be a "pure coincidence and luck",[50] and the continuous growth of space debris may expose the ISS to greater risks in the future.

In scenarios where the conjunction data is not precise enough to warrant CAMs, or where the close conjunction with space debris is not identified in time to enable CAMs, the control centre of the ISS may consider it the best course of action to move the crew into spaceships docked to the ISS to prepare for emergency evacuation.[51] For instance, in a close conjunction between the ISS and a piece of space debris on 15 November 2021, all seven astronauts onboard the ISS were forced to take shelter in their transport spacecraft until the immediate danger passed.[52] With the increase of crewed spaceflight in LEO, including the plans to construct commercial space stations in the future,[53] there is a growing need to properly deal with the risks posed by space debris to crewed spacecraft in order to ensure the safety of these missions.

2.2.3 Risks to the Ground

When objects in space re-enter Earth's denser atmosphere, the air drag converts their orbital energy into heat, and the heating process is usually sufficient to destroy these objects.[54] However, approximately 20-40% of the mass of larger-size spacecraft or rocket bodies, especially those parts made

47 NASA Orbital Debris Program Office (2020), *supra* note 44, p. 1.
48 Canadian Space Agency (CSA). (28 May 2021). Lucky strike: Canadarm2 Stays the Course After an Orbital Debris Hit. <https://www.asc-csa.gc.ca/eng/iss/news.asp#20210528>.
49 Ibid.
50 Datta, A. (3 June 2021). Op-ed | Damage to Canadarm2 on ISS Once Again Highlights Space Debris Problem. *SpaceNews*. <https://spacenews.com/op-ed-damage-to-canadarm2-on-iss-once-again-highlights-space-debris-problem/>.
51 NASA (2021), *supra* note 9.
52 Bartels, M. (16 November 2021). Space debris forces astronauts on space station to take shelter in return ships. *Space.com*. <https://www.space.com/space-debris-astronauts-shelter-november-2021>.
53 See e.g., Foust, J. (8 June 2023). From one, many: The race to develop commercial space stations and the markets for them. *SpaceNews*. <https://spacenews.com/from-one-many-the-race-to-develop-commercial-space-stations-and-the-markets-for-them/>.
54 ESA (2021), *supra* note 20.

of heat-resistant materials may survive the re-entry process and thus pose risks to the ground.[55] Since more than 70% of Earth's surface is covered by water and large portions of the land mass are inhabited, the risk to any single individual is estimated to be marginal.[56] However, between 100 and 200 metric tons of human-made objects re-enter the atmosphere every year in an uncontrolled fashion, and the risks posed by them cannot be completely ignored.[57] While there is to date no known injury caused by falling debris, a recent study estimates that there is an order of 10% chance that one or more casualties will be caused by re-entering rocket bodies over a decade.[58]

A prominent example of the risk to the ground is the re-entry of Cosmos 954 on 24 January 1978, a nuclear-powered reconnaissance satellite launched by the Soviet Union in September 1977.[59] Upon re-entry, the Cosmos 954 satellite disintegrated and scattered radioactive debris over a large area in the north of Canada.[60] Fortunately, the downfall of Cosmos 954 occurred in a relatively unpopulated area, and the crash did not cause any loss of life, physical injury, or direct damage to property.[61] Yet, due to the radioactive nature of the scattered debris, Canada undertook "operations directed at locating, recovering, removing and testing the debris and cleaning up the affected areas".[62] The purpose was to assess and minimise the hazard and to restore, to the greatest extent possible, the affected area to the condition that would have existed if the damage inflicted by the re-entry of Cosmos 954 satellite had not occurred.[63]

On 23 January 1979, Canada presented to the Soviet Union a claim for compensation in respect of the damage caused to Canada by the Cosmos

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55 Ibid.

56 Ibid.

57 Krag (2021), *supra* note 28, p. 259.

58 Byers, M., Wright, E., Boley, A., & Byers, C. (2022). Unnecessary Risks Created by Uncontrolled Rocket Reentries. *Nature Astronomy, 6*, pp. 1093–1097.

59 NASA Space Science Data Coordinated Archive (NSSDCA). Cosmos 954. <https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=1977-090A>.

60 Canada. (last modified 3 September 2019). Previous Nuclear Incidents and Accidents: COSMOS 954. <https://www.canada.ca/en/health-canada/services/health-risks-safety/radiation/radiological-nuclear-emergencies/previous-incidents-accidents/cosmos-954.html>.

61 Galloway, E. (1979). Nuclear Powered Satellites: The U.S.S.R. Cosmos 954 and the Canadian Claim. *Akron Law Review*, *12*(3), p. 401. See also Carpanelli, E., & Cohen, B. (2014). Interpreting "Damage Caused by Space Objects" Under the 1972 Liability Convention. In *56th Proceedings of International Institute of Space Law*, Eleven International Publishing, p. 36.

62 Canada. (1979). Claim against the Union of Soviet Socialist Republics for Damage Caused by Soviet Cosmos 954. Note No. FLA-268. In American Society of International Law. *International Legal Materials*, *18*(4), pp. 903-904.

63 Ibid.

954 satellite in the amount of around six million Canadian dollars.[64] The claim was based on the Liability Convention, the Outer Space Treaty, and general principles of international law.[65] The dispute was ultimately settled by a compensation protocol signed between Canada and the Soviet Union.[66] According to this Protocol, the Soviet Union agreed to pay Canada the sum of three million Canadian dollars "in full and final settlement of all matters connected with the disintegration of the Soviet satellite Cosmos 954".[67]

2.2.4 Risks to Space Sustainability

Since 2005, modelling studies of the population of objects in Earth orbit conducted by the IADC have concluded that "the space debris environment in certain regions below 2000 km altitude is currently unstable".[68] The IADC Study of 2013 finds that even with 90% compliance with commonly accepted space debris mitigation measures, the LEO debris population is expected to increase by approximately 30% in the next 200 years.[69] The Study thus concludes that "to stabilize the LEO environment, more aggressive measures, such as active debris removal, should be considered".[70]

Compared to LEO, the space debris situation in GEO is less pressing. A study published by Liou indicates that the projected debris population growth in medium Earth orbit (MEO) and GEO is more moderate than LEO, which thus suggests that emphasis should be first placed on the removal of debris in LEO.[71] The general consensus within the space community is also that the risk of collisions in GEO is significantly lower than that in LEO.[72] However, this does not mean that GEO is completely free from the space debris problem. Mejía-Kaiser observes that between 2008 and 2018, "there was a net average increase of nine space debris objects per year (five non-re-orbited satellites, plus four rocket bodies)" in GEO.[73] A study published by Oltrogge in 2018 finds that a collision is likely to occur every four years

64 Ibid, p. 899.
65 Ibid.
66 Disintegration of COSMOS 954 over Canadian territory in 1978: Protocol Between the Government of Canada and the Government of the Union of Soviet Socialist Republics, done on 2 April 1981. Available at: <https://www.unoosa.org/oosa/en/ourwork/spacelaw/nationalspacelaw/bi-multi-lateral-agreements/can_ussr_001.html>.
67 Ibid.
68 IADC (2022), *supra* note 3, p. 1.
69 IADC (2013), *supra* note 4, p. 1.
70 Ibid, p. 17.
71 Liou, J. C. (2011). An Active Debris Removal Parametric Study for LEO Environment Remediation. *Advances in space research*, *47(11)*, p. 1868. MEO is the region between LEO and GEO (from 2,000 km to 35,000 km).
72 Shadbolt (2023), *supra* note 15, p. 12.
73 Mejía-Kaiser, M. (2020). Out into the Dark: Removing Space Debris from the Geostationary Orbit-Revised. In *Proceedings of the International Institute of Space Law 2019*, Eleven International Publishing, pp. 523-524.

for one satellite out of the entire GEO active satellite population against a 1 cm object, and every fifty years against a 20 cm object.[74] These findings indicate that the Kessler syndrome can also be triggered in GEO.[75] Compared to LEO and GEO, the risk of collision in MEO is considerably lower due to its large volume and the relatively low number of satellites in this region.[76] Hence, debris in this region is generally not regarded as a priority for removal.

With the growing congestion in the orbital environment, especially in the LEO region where large constellations of satellites are to be deployed, the space debris situation is predicted to worsen. According to the IADC Report of 2023:

> "The environmental evolution results identify that a doubling of the space debris population may occur within 25 years and an increase of 10 times over the longer term due to an increasing rate of catastrophic collisions. Critically, even in the case of no further launches into orbit, it is expected that collisions among existing space debris objects will lead to a further growth in space debris population. Consequently, even with widespread adoption of these guidelines and recommendations, or even stricter behaviours, the consensus is that the environmental impacts cannot be removed completely and additional steps may need to be taken, such as enabling the technology for active debris removal."[77]

This worrisome finding reveals several items of important information. First, the space debris population is expected to grow exponentially, which means that the problem is becoming far more serious than the results of the projection made a decade ago in the IADC Study of 2013. Second, the fact that space debris will continue to increase even without new launches indicates that the number of space debris in orbit has already reached a tipping point where the number of space debris will continue to grow through a self-sustaining cascade of collisions. Thirdly, in reality, the situation will be worse than the no-launch baseline, as the increase in launch traffic will add even more objects into Earth orbit and further increase the risk of collision. This means that the Kessler syndrome will be much more easily triggered than the no-launch scenario. In this situation, the key to improve the orbital environment is to reduce the amount of existing debris by ADR.[78]

74 Oltrogge, D. L., Alfano, S., Law, C., Cacioni, A., & Kelso, T. S. (2018). A Comprehensive Assessment of Collision Likelihood in Geosynchronous Earth Orbit. *Acta Astronautica*, *147*, p. 316.

75 Ibid.

76 Shadbolt (2023), *supra* note 15, p. 13.

77 IADC (2023), *supra* note 23, p. 6.

78 JAXA (2023), *supra* note 29.

2.3 Overview of the Status of ADR and Issues relating to its Governance

The above section shows that the orbital environment is becoming unsustainable, and ADR is necessary to stabilise the space debris situation. ADR involves the removal of debris "using dedicated spacecraft that have been designed expressly for this purpose".[79] An end-to-end ADR operation consists of many components, including "launch, propulsion, proximity operations, rendezvous, contact (capture or attachment), and finally, deorbit or graveyard manoeuvre".[80] As ADR is challenging from a technological point of view, only a few spacefaring agencies have the potential capability to undertake these activities.[81] In recent years, Russia, the US, China and ESA have all engaged in rendezvous and proximity operations (RPO) where they manoeuvre one spacecraft to approach another spacecraft.[82] Rendezvous refers to a "process wherein two space objects (artificial or natural bodies) are intentionally brought close together through a series of orbital manoeuvres at a planned time and place".[83] Proximity operations refer to a "series of orbital manoeuvres executed to place and maintain a spacecraft in the vicinity of another space object (artificial or natural bodies) on a relative planned path for a specific time duration to accomplish mission objectives".[84] RPO technologies are often used for the docking of supply and crew change spacecraft with the crewed space stations, and these are also key enabling technologies for ADR missions.[85] Capturing a target debris object can be realised in various ways, such as the use of nets, harpoons, robotic arms, and magnetic docking plates.

One issue to be considered by ADR operators is the strategy of target selection. As there are various kinds of space debris in orbit, ranging from defunct spacecraft and rocket stages to debris fragments, which kind of space debris should be removed first? According to NASA, the selection of removal targets depends on the goal to be achieved: if the goal is to alleviate risks to the current fleet of operational satellites, then the removal of small but still damaging debris should be prioritised; if the goal is to stabilise the long-term growth of the debris population, then ADR techniques need

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79 Shadbolt (2023), *supra* note 15, p. 32.

80 Liou, J. C. (2012). Active Debris Removal and the Challenges for Environment Remediation. *28th International Symposium on Space Technology*, p. 5. <https://ntrs.nasa.gov/citations/20120013266>.

81 Undseth, M., Jolly, C., & Olivari, M. (2020). Space sustainability: The Economics of Space Debris in Perspective, *OECD Science, Technology and Industry Policy Papers*, No. 87, OECD Publishing, p. 32.

82 Byers & Boley (2023), *supra* note 25, p. 343.

83 Sec. 3.12, ISO 24330: 2022 "Space systems — Rendezvous and Proximity Operations (RPO) and On Orbit Servicing (OOS) — Programmatic principles and practices", published on 1 July 2022. For more discussion see Chapter 4 Section 4.2.3 *infra*.

84 Sec. 3.12, ISO 24330, ibid.

85 Ibid, pp. 343-344.

to focus on large, massive objects such as defunct rocket bodies and non-functional satellites.[86]

The general consensus of the international space community is that the priority of ADR should be given to the removal of large, massive objects located in congested orbital areas.[87] This is because the higher the spatial density, the higher the probability of collision events with other objects.[88] In addition, the greater the mass of the derelict objects, the greater the amount of debris fragments that can be produced once such objects explode or collide with other space debris, which can potentially cause rapid spikes in the space debris population.[89] As pointed out in the International Academy of Astronautics (IAA) *Situation Report on Space Debris* of 2016, catastrophic collisions involving large space objects in orbit will, within a few decades, become the dominant source of the debris population, as the fragments created by these collisions may trigger further catastrophic collisions.[90] The Report follows by submitting that "[t]he only way to prevent the on-set of collisional cascading is to prevent collisions between large derelicts which may be enabled through active removal of mass from orbit".[91] In addition, the removal of large objects is considered to be more technologically feasible and economically efficient than the removal of small objects.[92]

Calculations by scientists show that to maintain an orbital environment similar to that of the current situation, it is necessary to remove five to ten pieces of large space debris from congested orbits per year.[93] However, as the calculation is made on the assumption of the current launch traffic and a high compliance rate with post-mission disposal measures,[94] more large objects may need to be removed from orbit with the deployment of large

86 NASA Orbital Debris Program Office. Debris Remediation. <https://orbitaldebris.jsc.nasa.gov/remediation/>.

87 JAXA (2023), *supra* note 29. See also ESA. Active Debris Removal. <https://www.esa.int/Space_Safety/Space_Debris/Active_debris_removal>.

88 Ibid.

89 Ibid. Shadbolt (2023), *supra* note 15, p. 9.

90 Bonnal, C. & McKnight, D. S. (Eds.). (August 2017). *IAA Situation Report on Space Debris – 2016*, International Academy of Astronautics, p. 14.

91 Ibid.

92 May, C. (January 2021). Triggers and Effects of an Active Debris Removal Marketplace. *The Aerospace Corporation*, p. 2. See also Pulliam, W. (2011). *Catcher's Mitt Final Report of DARPA*. Defense Advanced Research Projects Agency (DARPA), p. 2: "Although the greatest threat to operational spacecraft stems from medium debris (defined as 5 mm – 10 cm), no reasonable solution was found to effectively remove this size of debris object. Compliance with existing international debris mitigation guidelines coupled with the pre-emptive removal of the sources of future medium debris, is by far the most cost-effective strategy."

93 JAXA (2023), *supra* note 29. ESA, *supra* note 87. See also UK. (8 February 2022). Statement at Scientific and Technical Sub-committee of the COPUOS: Space debris. <https://www.gov.uk/government/news/uk-statement-at-scientific-and-technical-sub-committee-of-the-committee-on-the-peaceful-uses-of-outer-space-copuos-space-debris>.

94 JAXA, ibid.

constellations and the continuous growth of the space debris population. Due to the self-sustaining generation of space debris, ESA's internal studies show that "continuous removal actions starting in 2060 will only have 75% of the beneficial effect compared to an immediate start".[95] Therefore, the international community can respond more effectively to the space debris problem by starting to engage in the removal of large objects from space. Section 2.3.1 will introduce the current efforts made towards debris removal and Section 2.3.2 will outline the issues relating to ADR that require an answer from international space law for their governance.

2.3.1 Current Status of ADR Missions

The above discussion introduces why space debris is an issue and the necessity of ADR to address this issue. At the moment, ADR activities are still in a nascent phase, but they are in the process of becoming a reality. As noted in the IADC ADR Statement:

> "Several IADC member agencies, as well as other organizations, are investigating techniques and technologies that have the potential to support debris removal, or are developing pioneering missions, although routine debris removal operations are unlikely to commence in the near future."[96]

To present an overview of the current status of ADR, several pioneering ADR missions will be introduced in the order of their (planned) mission launch time. This will start with two ADR technology demonstration missions using replica debris objects, which are the RemoveDebris mission and the ELSA-d mission. Then, four ADR missions to remove existing derelict objects from orbit will be introduced, including China's Shijian-21 mission launched in 2021 and three planned ADR missions initiated by the Japan Aerospace Exploration Agency (JAXA), ESA and the United Kingdom (UK) Space Agency to be launched in the coming years.

Launched in 2018, RemoveDebris was the first mission to successfully demonstrate in orbit a series of ADR technologies. The mission was developed by a consortium led by the Surrey Space Centre, and the consortium members included Airbus Defence and Space, Surrey Satellite Technology Ltd (SSTL), and other partners.[97] The mission used a satellite platform (approximately 100 kg) as a mothercraft from which two CubeSats were

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95 ESA, *supra* note 87.

96 IADC (2022), *supra* note 3, p. 1.

97 Surrey Space Center. RemoveDEBRIS. <https://www.surrey.ac.uk/surrey-space-centre/missions/removedebris>. For more details of the RemoveDEBRIS mission see Aglietti, G. S., Taylor, B., Fellowes, S., Ainley, S., Tye, D., Cox, C., Zarkesh, A., Mafficini, A., Vinkoff, N., Bashford, K., Salmon, T., Retat, I., Burgess, C., Hall, A., Chabot, T., Kanani, K., Pisseloup, A., Bernal, C., Chaumette, F., Pollini, A., & Steyn, W. H. (2020). RemoveDEBRIS: An In-Orbit Demonstration of Technologies for the Removal of Space Debris. *The Aeronautical Journal*, *124*(1271), pp. 1-23

ejected to be used as pseudo-debris targets.[98] After deployment, the mothercraft undertook four experiments: a net capture experiment, a vision-based navigation (VBN) experiment, a harpoon experiment, and a dragsail experiment for end-of-mission deorbiting of the platform.[99] The first three missions were successfully completed. The net and the harpoon were both proven as viable methods to capture space debris.[100] The VBN experiment tested technologies for the observation of debris and the determination of its distance and spin rate.[101] The drag-sail experiment was used to test post-mission disposal techniques.[102] Though some anomalies were manifested in this final experiment, the whole process from development to operation had provided important lessons which later enabled the successful production and operation of a new generation of drag-sails.[103] The mission was a success both in technological demonstration and in raising awareness of the issue of space debris in the general public.[104]

ELSA-d (End of Life Services by Astroscale-demonstration) is a technology demonstration mission performed by Astroscale, a leading ADR company founded in 2013 and headquartered in Japan.[105] Astroscale aims to contribute to debris removal through the provision of two kinds of services: end-of-life (EOL) and ADR.[106] The EOL service concerns the removal of future-launched spacecraft equipped with a docking plate (DP) for semi-cooperative removal, which targets the commercial large constellation market and its primary clients will be commercial satellite operators.[107] The ADR service concerns the removal of existing objects in space that are fully non-cooperative.[108] The primary target clients of the ADR service will be public actors since most of the existing debris objects "are the result of institutional missions and thus will be a market driven by governments and space agencies".[109]

Launched in March 2021, the aim of the ELSA-d mission is to demonstrate technologies and capabilities critical to EOL and ADR, including client

98 Saunders, C. (9 February 2015). RemoveDebris Mission: Briefing to UNCOPUOS. <https://www.unoosa.org/pdf/pres/stsc2015/tech-42E.pdf>.
99 Aglietti *et al.* (2020), *supra* note 97, p. 4.
100 Ibid, p. 20.
101 Ibid.
102 Ibid.
103 Ibid, pp. 20-21.
104 Shadbolt (2023), *supra* note 15, p. 32.
105 Astroscale. About. <https://astroscale.com/about-astroscale/about/>.
106 Weeden, C., Blackerby, C., Forshaw, J., Martin, C., Lopez, R., Yamamoto, E., & Okada, N. (2019). Development of Global Policy for Active Debris Removal Services. *First International Orbital Debris Conference*, p. 2.
107 Ibid.
108 Blackerby, C., Okamoto, A., Fujimoto, K., Okada, N., Forshaw, J. L., & Auburn, J. (2018). ELSA-d: An In-Orbit End-of-Life Demonstration Mission. In *69th International Astronautical Congress*, p. 1.
109 Weeden *et al.* (2019), *supra* note 106, pp. 1-2.

search, inspection, rendezvous, non-tumbling and tumbling docking, and de-orbit.[110] The mission consists of two satellites – a servicer satellite and a client satellite, with the latter servicing as a piece of replica debris installed with an Astroscale DP that enables magnetic docking.[111] The technologies tested in the ELSA-d program will be applied in Astroscale's other programs such as ELSA-M (End-of-Life Services by Astroscale-Multi), which is a commercial EOL service under development to capture and remove multiple satellites equipped with DPs in a single mission.[112]

While the above RemoveDebris and ELSA-d missions both target replica debris, the removal of existing debris from orbit has also been achieved. In October 2021, China launched the Shijian-21 satellite, which two months later approached and docked with a defunct Beidou-2 G2 navigation satellite.[113] In January 2022, Shijian-21 performed an engine burn, towing Beidou-2 G2 about 3000 km above the GEO belt, which is a very high orbit beyond the usual "graveyard" orbit of 300 km above GEO, and thus effectively moved the defunct satellite out of harm's way.[114] Shijian-21 then undocked from Beidou-2 G2 and returned back to GEO.[115]

While Shijian-21 was developed by China's State-owned company Chinese Aerospace Science and Technology Corporation (CASC),[116] the ADR projects planned by JAXA, ESA and the UK Space Agency involve more participation of the private sector. The Commercial Removal of Debris Demonstration (CRD2) is a JAXA program to actively remove large debris of Japanese origin in cooperation with private companies.[117] It aims to acquire ADR technologies to address the increasingly critical problem of space debris and to support the commercial activities of Japanese companies in the ADR market.[118] The CRD2 program will be carried out in two

110 Astroscale. (2022). ELSA-d Press Kit 2022, p. 4. <https://astroscale.com/wp-content/uploads/2022/02/ELSA-d-Press-Kit-2022-Lo-Res.pdf>.

111 Ibid.

112 Astroscale. ELSA-M. <https://astroscale.com/elsa-m>.

113 Jones, A. (27 January 2022). China's Shijian-21 Towed Dead Satellite to a High Graveyard Orbit. *SpaceNews*. <https://spacenews.com/chinas-shijian-21-spacecraft-docked-with-and-towed-a-dead-satellite/>.

114 Ibid. See also Byers & Boley (2023), *supra* note 25, p. 314.

115 Ibid.

116 Zhao, L. (25 October 2021). Satellite to Facilitate Space Debris Oversight. *China Daily*. <https://www.chinadaily.com.cn/a/202110/25/WS617603faa310cdd39bc70f2f.html>. CASC is a Chinese State-owned enterprise and the main contractor of China's governmental space programs. See CASC. About. <http://english.spacechina.com/n16421/index.html>.

117 JAXA. CRD2. <https://www.kenkai.jaxa.jp/eng/crd2/>.

118 Ibid.

phases.[119] Astroscale has been selected as the contractor for Phase-I of the program, which plans to launch its ADRAS-J (Active Debris Removal by Astroscale-Japan) satellite in 2023 to rendezvous with a discarded Japanese rocket upper stage, demonstrate proximity operations and acquire images of the target.[120] CRD2 Phase-II consists of the capture and removal of the target debris object and it will be launched in 2026.[121]

The ClearSpace-1 mission was procured by ESA in 2020 with a consortium led by Swiss startup ClearSpace to de-orbit an ESA-owned item of debris from space.[122] The mission is scheduled to be launched in 2025 and the target is a Vespa (Vega Secondary Payload Adapter) upper part with a mass of 112 kg.[123] The selected target is close in size to a small satellite and its relatively simple shape and sturdy construction make it an appropriate first goal, before progressing to more complex missions such as multi-object capture.[124] The ClearSpace-1 servicer is a medium-sized spacecraft equipped with four tentacles large enough to embrace and grip the target.[125] In addition to the removal of space debris and the verification of relevant technologies, the ClearSpace-1 mission also aims to "open a new market for in-orbit servicing and debris removal".[126] As ESA explains, paying for a service contract rather than directly procuring and running the entire mission represents a new business approach of ESA, which is intended as the first step towards establishing a new commercial space sector.[127]

The UK's first national space debris removal mission is planned to be launched in 2026. In October 2021, the UK Space Agency announced "a range of different initiatives aimed at supporting safe and sustainable

119 For a detailed discussion of the CRD2 program see Yamamoto, T., Matsumoto, J., Okamoto, H. Yoshida, R., Hoshino, C., & Yamanaka, K. (2021). Pave the way for Active Debris Removal Realization: JAXA Commercial Removal of Debris Demonstration (CRD2). In *Proceedings of 8th European Conference on Space Debris*, pp. 1-8.

120 Astroscale. (22 August 2022). Astroscale Selected as Contract Partner for Front-Loading Technology Study in Phase II of JAXA's Commercial Removal of Debris Demonstration Project. <https://astroscale.com/astroscale-selected-as-contract-partner-for-front-loading-technology-study-in-phase-ii-of-jaxas-commercial-removal-of-debris-demonstration-project/>.

121 Henry, C. (12 February 2020). Astroscale Wins First Half of JAXA Debris-Removal Mission. *SpaceNews*, <https://spacenews.com/astroscale-wins-first-half-of-jaxa-debris-removal-mission/>.

122 ESA. (2020). ESA Purchases World-First Debris Removal Mission from Start-up. <https://www.esa.int/Safety_Security/ESA_purchases_world-first_debris_removal_mission_from_start-up>.

123 Ibid.

124 Ibid.

125 Biesbroek, R., Aziz, S., Wolahan, A., Cipolla, S. F., Richard-Noca, M., & Piguet, L. (2021). The ClearSpace-1 Mission: ESA and ClearSpace Team up to Remove Debris. In *Proceedings of 8th European Conference on Space Debris*, p. 2.

126 Ibid, p. 1.

127 ESA (2020), *supra* note 122.

space operations", including the research of a UK mission to clear hazardous space junk.[128] In September 2022, the UK Space Agency awarded £4 million to two UK companies, namely ClearSpace UK (the UK subsidiary of ClearSpace) and Astroscale UK (the UK and European subsidiary of Astroscale), for the design of missions to remove two defunct UK-registered satellites from LEO.[129] This design phase will finish with a preliminary design review, and upon its completion, the two companies, along with other industry partners, will receive further funding for developing this UK ADR mission.[130]

Besides the above missions and mission plans, NASA also has research projects under way for ADR technologies.[131] All these initiatives indicate a fast-growing concern about the increased collision risks resulting from the growth of space debris which may, in turn, lead to the further creation of space debris. This concern motivates States and space agencies to invest in ADR technologies and develop ADR missions. Driven by the common interest to preserve space sustainability, the international community may be able to prevent the "tragedy of the commons" from happening in space. The current missions represent a good start, but more efforts are needed, which will be discussed in the next section.

2.3.2 Issues relating to the Governance of ADR

It can be seen from the above ADR missions that China, JAXA, ESA and the UK Space Agency have all chosen massive objects as their mission targets, being either a defunct satellite, a discarded rocket stage, or in the case of ClearSpace-1, an item of debris close in size to a small satellite. Their target selection strategies indicate that ADR missions will start with the removal of large debris, which is in line with the aforementioned consensus view of the space community that ADR activities should prioritise the removal of large and massive objects, as they are the major source of fragmentation debris in the long term. Since large objects are usually tracked and catalogued, it is easier to identify their owners to address the relevant legal issues regarding their removal.

It was predicted by Masson-Zwaan and Hofmann in 2019 that the first ADR missions would likely focus on objects owned by the institutions aiming at

128 UK Space Agency. (26 October 2021). Press Release: UK Working with Global Partners to Clear up Dangerous Space Debris. <https://www.gov.uk/government/news/uk-working-with-global-partners-to-clear-up-dangerous-space-debris>.

129 UK Space Agency. (26 September 2022). UK Builds Leadership in Space Debris Removal and In-Orbit Manufacturing with National Mission and Funding Boost. <https://www.gov.uk/government/news/uk-builds-leadership-in-space-debris-removal-and-in-orbit-manufacturing-with-national-mission-and-funding-boost>.

130 Ibid.

131 Byers & Boley (2023), *supra* note 25, p. 315.

removing them.[132] The ADR missions mentioned earlier affirm this prediction, as all these missions choose targets that are owned or registered by the institutions engaging in or procuring the missions. This could help to avoid some complex legal questions such as jurisdiction and ownership.[133] However, there is no guarantee that every State, or space agency, will effectively remove its own debris. With the growing congestion in Earth orbit and the increasing necessity of ADR activities to stabilise the orbital environment, the removal of a space object under the jurisdiction of another State may need to be contemplated in the future. For instance, an operator of a large constellation may be interested in keeping a certain orbital plane free of debris to safeguard the safety of its satellites, for a collision caused by a debris item to one satellite may lead to knock-on collisions involving other satellites in the constellation, putting at stake the operator's investment.[134] As opined by Ted Muelhaupt, no one has a higher vested interest in keeping their orbits clean than operators of large constellations.[135] Owing to such interest, States with projects to deploy large constellations in space such as China can have a strong impetus to clear the orbits for the safe operation of their constellations.[136] With space becoming increasingly congested in the future, it can also be expected that States would wish to remove dangerous debris of other States when such debris threatens their key assets in space. Therefore, questions may arise as to the legal status of space debris, which State can exercise jurisdiction over debris objects to determine issues relating to their removal, and whether a State may remove a debris object under the jurisdiction of another State. How these issues are addressed under the current legal regime will be assessed in the next chapter.

As mentioned earlier, around five to ten large objects need to be removed from space per year to stabilise the orbital environment. The leading ADR missions demonstrate a promising trend towards space debris remediation, but it is still uncertain whether ADR missions will be conducted at a sufficient rate to halt the growth of space debris. In addition, while ADR is indispensable for a stable orbital environment, what is even more important is space debris mitigation, for if the future growth of space debris cannot be

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132 Masson-Zwaan, T. L. & Hofmann, M. (2019). *Introduction to Space Law*. Wolters Kluwer, p. 119.

133 Ibid.

134 Palmroth, M., Tapio, J., Soucek, A., Perrels, A., Jah, M., Lönnqvist, M., Nikulainen, M., Piaulokaite, V., Seppälä, T., & Virtanen, J. (2021). Toward Sustainable Use of Space: Economic, Technological, and Legal Perspectives. *Space Policy*, *57*, 101428, p. 11.

135 Werner, D. (15 November 2018). Will Megaconstellations Cause a Dangerous Spike in Orbital Debris? *SpaceNews*, <https://spacenews.com/will-megaconstellations-cause-a-dangerous-spike-in-orbital-debris/>.

136 China currently has plans for two large constellation projects, namely the 13,000-satellite Guowang (SatNet) project and the 12,000-satellite G60 Starlink project. See e.g., Jones, A. (29 December 2023). First Satellite for Chinese G60 Megaconstellation Rolls off Assembly Line. *SpaceNews*. <https://spacenews.com/first-satellite-for-chinese-g60-megaconstellation-rolls-off-assembly-line/>.

effectively mitigated, most of the required ADR effort would go to compensate for the generation of new debris.[137] Therefore, it is essential to ensure that States undertake appropriate measures to limit the creation of new space debris. Moreover, the existence of an obligation of debris mitigation is logically connected to that of debris remediation because if there is no legal duty to prevent the creation of space debris, then by extension, it would be difficult to argue that there exists an obligation to actively remove space debris.[138] These raise the question as to whether the current international legal framework governing space activities requires States to mitigate and remediate space debris.

All ADR techniques require some level of interaction with a space debris object, and this involves inherent risks of collision, especially during the RPO and contact phases where the distance between the removal spacecraft and the target debris object is relatively small. In particular, it should be noted that most existing debris objects are non-cooperative, meaning that they have neither the ability to communicate with the removal spacecraft nor dedicated interfaces for capture and physical connection.[139] In addition, the target debris objects are possibly tumbling, which makes it even more challenging to capture them.[140] In the worst case, the removal spacecraft could collide with the target debris object, which may create a debris cloud that closes off a valuable orbit for decades.[141] This debris cloud may cause damage to other spacecraft in orbit and accelerate the Kessler Syndrome.[142]

A further risk is that in an ADR operation, the removal spacecraft may need to change trajectories more frequently and on a larger scale than many other conventional space missions to approach, capture and remove the target debris object from congested orbital areas.[143] The need to cross orbits on the way up or down can increase the risk of collision with other objects in

137 ESA, *supra* note 87.

138 Mudge, A. G. (2022). Incentivizing 'Active Debris Removal' Following the Failure of Mitigation Measures to Solve the Space Debris Problem: Current Challenges and Future Strategies. *Air Force Law Review*, *82*(1), p. 123.

139 May, C. (2021). Triggers and Effects of an Active Debris Removal Marketplace. *The Aerospace Corporation*, p. 5.

140 Ibid.

141 Buckley, K. (2022). Active Debris Removal Rule No. 1 Must be "Do No Harm". *Aerospace America*. <https://aerospaceamerica.aiaa.org/departments/active-debris-removal-rule-no-1-must-be-do-no-harm/>.

142 Ibid.

143 Sec. 4.3.1, Japanese *Guidelines on a License to Operate a Spacecraft Performing On-Orbit Servicing*, published on 10 November 2021 by the National Space Policy Secretariat of the Cabinet Office of Japan. <https://www8.cao.go.jp/space/english/stm/index.html>. This document will be discussed in more detail in Chapter 5 Section 5.2.3.

orbit.[144] Like collisions between the removal spacecraft and the target debris object, collisions with objects of third parties could also trigger a chain reaction of further cascading collisions. Therefore, as submitted by Buckley, the primary rule for ADR activities should be to "do no harm", otherwise these activities may deteriorate rather than remediate the current space debris situation.[145] In addition, when the target of removal is a massive object in LEO, its de-orbiting may likely cause damage to the ground if such object cannot completely burn up in the process of atmospheric re-entry. In light of the inherent risks involved in ADR activities, the international liability regime for damage caused by these activities should be examined. The questions include whether and how liability can be established for the damage caused to other spacecraft, for damage caused on the ground, and for the generation of debris fragments that subsequently cause further damage to others.

Besides safety risks, ADR activities may also involve security risks due to the dual-use potential of the ADR spacecraft. As stated in a Report published by the UN Secretary-General in 2021:

> "Dual-use co-orbital systems include on-orbit servicing and active debris removal. On-orbit servicing satellites can refuel, repair and extend the life of other satellites. Active debris removal systems are intended to deorbit non-operational satellites. On-orbit demonstrations of the latter systems have used nets, harpoons, magnets or robotic arms. While such systems are regarded as important for ensuring the sustainability of outer space activities, such capabilities are inherently of dual use and could be used to damage, degrade or destroy a satellite."[146]

Due to its dual-use potential, the removal spacecraft may become a source of security concern. The European Union (EU) states that operations employing dual-use technologies such as ADR may be perceived as a threat and be (mis-)understood as hostile actions, especially in scenarios where "the intention behind the manoeuvre is not properly communicated".[147] Similarly, the view of the UK is that while ADR capabilities "offer significant opportunities to improve the space environment", these capabilities

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144 UN Doc. A/AC.105/C.1/2012/CRP.16 (27 January 2012). Active Debris Removal — An Essential Mechanism for Ensuring the Safety and Sustainability of Outer Space: A Report of the International Interdisciplinary Congress on Space Debris Remediation and On-Orbit Satellite Servicing, p. 32.

145 Buckley (2022), *supra* note 141.

146 UN Doc. A/76/77 (13 July 2021), Report of the UN Secretary-General on Reducing space threats through norms, rules and principles of responsible behaviours ("UNSG Report of 2021"), p. 6.

147 The EU. (13 September 2022). Open Ended Working Group on reducing space threats through norms, rules and principles of responsible behaviours – EU Statement. <https://www.eeas.europa.eu/delegations/un-geneva/open-ended-working-group-reducing-space-threats-through-norms-rules-and_en?s=62>.

could be repurposed to attack a satellite.[148] In view of the dual-use character of ADR technologies and capabilities, it is important to understand how military activities are regulated under the current international legal framework for space activities and how this may impact ADR activities, as well as whether there are guidelines and principles to address the dual-use concerns over ADR.

2.4 Chapter Conclusion

Space debris refers to non-functional, human-made objects that are in Earth orbit or re-entering the atmosphere, such as rockets and satellites that have completed their missions, as well as objects that are fragmented or disintegrated from rockets and satellites. These debris objects are flying around the Earth at high speed and, because of their velocity, they pose collision risks to operational satellites and crewed spacecraft. Once a collision occurs, more space debris could be created, which can further worsen the orbital environment, especially when catastrophic collisions are concerned where massive objects are fragmented into pieces. This self-sustained cascading collision process is known as the Kessler syndrome, and it can lead to the run-away growth of space debris. Space debris mitigation is important to limit the generation of new debris, but this alone is not sufficient to stabilise the orbital environment, as even in the scenario of no future launches, the debris population will continue to grow. The problem is complicated by the deployment of large constellations consisting of hundreds and thousands of satellites in orbit, which can further increase orbital congestion and collision risks. To counteract the trend of the Kessler syndrome, ADR operations are needed to remove massive derelict objects from orbit before they become a future source of more debris. Some projects are currently taking place, but there is still a long way to go to reach the goal of removing five to ten large objects from space per year. As space debris is becoming a pressing issue, this dissertation will assess *whether the current international framework governing space activities imposes an obligation on States to mitigate and remove space debris.* [*Issue 1*].

ADR operations involve inherent risks of collision due to the technical complexity of these operations, and collisions may occur either between the removal spacecraft and the target debris object, or between these objects with space objects of third parties. The fragments generated by these collisions may cause subsequent damage. Therefore, it is important to understand *the international liability regime for damage caused as a result of space activities and the implications of this regime on ADR activities*. [*Issue 2*]

148 The UK. (14 September 2022). Statement by the United Kingdom at the 2nd session of OEWG. <https://meetings.unoda.org/meeting/57866/statements>.

An examination of the leading ADR missions shows that States and space agencies are currently focusing on the removal of their own space debris. The growing amount of space debris and the increasing congestion in Earth orbit can lead to a greater necessity for ADR operations, and the removal of space objects under the jurisdiction of another State may be needed in the future, such as when a State fails to effectively remove its dangerous debris. Therefore, the question is *whether the current legal regime allows the removal by one State of space debris under the jurisdiction of another State.* [*Issue 3*]

Finally, ADR technologies have an inherent dual-use nature, meaning that the technologies developed to remove debris, such as the robotic arm or other mechanisms designed to capture the target debris object, can also be used for hostile purposes such as to damage and destroy operational satellites of other States. Therefore, a key issue to consider is *how the current legal framework addresses the dual-use potential of ADR activities.* [*Issue 4*]

These four issues will be discussed in the following three chapters, including how these issues are regulated under the UN space treaties and general international law (Chapter 3), what is the contribution of non-legally binding instruments to the governance of these issues (Chapter 4), and how the current international legal framework for space activities may move forward to better address these issues (Chapter 5).